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CORRECTIONS AND EMENDATIONS

Contributors to Volume 50 have been invited to send corrections and emendations to be made in their paper, and the volume has been scanned with some care. Corrections and insertions are as follows:

Page 58, *add* reference: Burckhardt, Carlos (1930) *Etude synthétique sur le Mésozoïque méxicain*, Soc. Paléont. Suisse, Mém., vols. 49–50, 280 pages, 11 tables, 32 figures.

" 61, under "*Phylloceras*" sp., *for* holotype, *read* specimen.

" 234, *add* footnote: *Paper contains analyses used in this study.

" 699, line 19, *after* complete columnar section, *add* (Jenkins and Wilson, 1920; Darton, 1925).

" 759, *add* Darton, N. H. (1925) *Résumé of Arizona geology*, Ariz. Bur. Mines, Bull. 119, p. 285–286.

" 802, line 4, *for* metric ton, *read* cubic meter.

" 803, last line, *for* basic, *read* acid.

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Cambrian formations of southwestern Alberta and southeastern British Columbia. CHARLES DEISS	951–1026	8	6	0.55	0.80

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UPPER JURASSIC AMMONITES FROM MEXICO

BY RALPH W. IMLAY

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ABSTRACT

Near-shore deposits of Upper Jurassic age occur along the margin of the former Coahuila Peninsula of northern Mexico and along the site of the Sierra Madre Oriental in eastern Mexico. These deposits contain a mixed bivalve and ammonite fauna whose description will furnish a means of correlation between various facies in the Mexican Geosyncline. Studies of the ammonites, undertaken in the present paper, confirm the validity of most of Burckhardt's stratigraphic divisions for the off-shore deposits and show that they can be traced into the near-shore deposits. New information concerning the stratigraphic ranges of certain ammonite genera and the discovery of the presence of other genera have made necessary slight changes in Burckhardt's subdivisions and have shown that the succession of ammonite assemblages in the Upper Jurassic of Mexico agrees fairly well with that of the Mediterranean province.

INTRODUCTION

Present knowledge of the Upper Jurassic faunas of the Mexican Geosyncline is due principally to Burckhardt (1906, 1912, 1919) who made monographic studies of the ammonites from the regions of Mazapil in northern Zacatecas, Symón in eastern Durango, and San Pedro del Gallo in northeastern Durango. An earlier paper by Castillo and Aguilera (1895) on the fossil faunas of the Sierra de Catorce in northern San Luis Potosí was revised in part by Burckhardt (1930, p. 79, 80). The former authors described a few pelecypods and brachiopods, as well as ammonites, but Burckhardt described only ammonites although he mentioned pelecypods in stratigraphic discussions. A near-shore mollusk fauna of the northern edge of the Mexican Geosyncline, near Torcer, Texas, was described by Cragin (1905), and some ammonites from the same area have recently been described by Albritton (1937). Burckhardt's last monograph (1930) summarizes all the earlier work.

Studies of the mountain ranges bordering the Coahuila Peninsula by Kellum (1932, 1936) and the writer (1936, 1937) revealed thick Jurassic sections in the centers of the highest uplifts. The Jurassic beds were found to represent near-shore deposits and to contain a mixed bivalve and ammonite fauna. The study of this mixed fauna was deemed desirable as a means of correlating near-shore with off-shore deposits, as a foundation for future studies in other parts of the Mexican Geosyncline, and as a contribution to the knowledge of Jurassic faunas. Preliminary to the laboratory studies of the fauna, the writer visited several type localities described by Böse and Burckhardt in northern Mexico, checked the geology, and made collections of type fossils. Additional collections were made from fossil localities previously discovered by Kellum in the Sierra de Jimulco and Sierra de Mapimí, and several new localities were discovered in the course of reconnaissance studies in southern Coahuila and northern Zacatecas. The present paper deals only with the ammonites. It confirms the validity of most of Burckhardt's stratigraphic divisions based on ammonites for the off-shore deposits of the Upper Jurassic and shows that they can be traced into the near-shore deposits.

ACKNOWLEDGMENTS

The fossils described in this report were collected during the summers of 1931 to 1937 in the course of stratigraphic and structural studies in northern Mexico. The field and laboratory work were financed jointly by the Penrose Bequest of the Geological Society of America and by the Horace H. Rackham School of Graduate Studies of the University of Michigan. This paper is one of a series dealing with the Jurassic and Cretaceous faunas of Mexico.

STRATIGRAPHIC SUMMARY

The Upper Jurassic stratigraphy of north-central Mexico has recently been summarized by the writer in a paper comparing the facies of sedimentation in the Mexican Geosyncline (Imlay, 1938). The near-shore deposits have been called La Gloria and La Casita formations, and the off-shore deposits the Zuloaga limestone and La Caja formation. La Gloria formation and Zuloaga limestone are probably equivalent and are mainly, or entirely, of Oxfordian age. The Zuloaga limestone is identical with the "Nerinea" limestone of Burckhardt. La Casita and La Caja formations likewise are in general equivalent and represent the younger Jurassic stages, although in some sections the highest beds of La Casita formation may not include the Tithonian. Near-shore deposits of Upper Jurassic age have been found along the margin of the former Coahuila

Peninsula (Kellum, Imlay, and Kane, 1936, p. 978-980) and along the site of the Sierra Madre Oriental. The Coahuila Peninsula was probably the principal source of sediment of the north-central part of the Mexican Geosyncline during the Upper Jurassic and Neocomian. However, the deposits along the Sierra Madre Oriental must have had a different source. Burckhardt (1930, p. 84-91, 101) has summarized the work of several geologists in that region and has concluded that there must have been an island in the vicinity of Miquihuana and a large landmass, probably a peninsula, farther east along what is now the coastal plain. He recognized that this landmass ended toward the south in the State of Vera Cruz and Hidalgo and was partially broken on the east by an embayment in the region of Tampico (Burckhardt, 1930, p. 94-96). Later fossil discoveries by Hegwein (Burckhardt, 1930, p. 266; Kellum, 1937, p. 70, 86-91) in the San Carlos Mountains indicate the presence of Upper Jurassic deposits on the site of the Coastal Plain and may be taken as evidence against the presence of a continuous, large landmass in eastern Mexico during Upper Jurassic time. The near-shore deposits found in the Sierra Madre Oriental might have been derived from islands situated on or at the eastern margin of the cordillera and forming an archipelago, such as has been suggested by Böse (1927, p. 81-82). These islands might, of course, be the continuation of a peninsula extending southward from the main landmass in the region of Texas.

EUROPEAN EQUIVALENTS

The Upper Jurassic ammonite assemblages of Mexico are sufficiently well known to permit comparisons of the Mexican section with the standard European sections. For purposes of discussion and correlation it is convenient to use the large stratigraphic subdivisions called "stages." The difficulty in using stage-names lies in the disagreement among authorities as to the proper limits of the stages, and it seems unlikely that the attempt of any one worker to secure a uniform terminology would meet with general acceptance. The matter will probably have to be ruled on by an international committee. Until uniformity is attained it will be necessary for each author to define his usage. In the present paper the works of Spath (1933, p. 864, 872) are followed for the definition of European stage names. For purposes of comparison, several recent usages of Upper Jurassic stage-names are given in Table 1.

FOSSILS

LOCALITIES

Sierra de Parras.—The position of the fossil localities in the Sierra de Parras is indicated in published papers (Imlay, 1936, fig. 3; 1937, fig. 3).

TABLE 1.—*Comparison of Upper Jurassic stage-names*

After L. F. Spath (1933) Tables I and II		After C. Burckhardt (1930) Table 6 and p. 42	After compilation by E. Daeque (1934) p. 546–547	Ammonite zones after L. F. Spath (1933) Tables I and II
Tithonian		Upper Portlandian	Upper Tithonian	*privasensis*
Portlandian				*giganteus scythicus*
Kimmeridgian	Neokimmeridgian or Bononian	Lower Portlandian	Lower Tithonian	*contiguus*
	Mesokimmeridgian or Havrian			*steraspis eudoxus*
	Eokimmeridgian or Sequanian	Kimmeridgian	Upper Kimmeridgian	
			Middle Kimmeridgian	*tenuilobatus altenensis*
			Lower Kimmeridgian	
Oxfordian	Neoxfordian or Argovian	Upper Oxfordian	Upper Oxfordian	*bimammatum transversarium perarmatum*
			Middle Oxfordian	
	(Mesoxfordian) or Divesan	Lower Oxfordian	Lower Oxfordian	*cordatus lamberti athleta*
	(Eoxfordian) or Callovian	Callovian	Callovian	*anceps calloviensis*
Bathonian		Bathonian	Bathonian	*bullatus*

LOCALITY 34: About 1⅕ miles southwest of Rancho Astillero, on trail to La Unión. Fossils occur in a thin lens of dark-gray limestone enclosed in gray and pinkish shale. Represents beds with *Durangites*. Fossils: *Durangites astillerensis* Imlay, n. sp.; *D.* cf. *acanthicus* Burckhardt; *D.* sp.; *Hildoglochiceras grossicostatum* Imlay, n. sp.; *H. ecarinatum* Imlay, n. sp.

LOCALITY 43: Right bank of Cañón de la Casita, about three-quarters of a mile north of Rancho La Casita. Fossils occur in limestone concretions in black shale of upper 83 feet of measured section (Imlay, 1937, p. 602). Probably represents beds with *Glochiceras fialar* and *Waagenia*. Fossils: *Aulacosphinctoides*? (*Subdichotomoceras*?) sp.; *A.*? aff. *diversecostatus* (Burckhardt); *Waagenia parrasensis* Imlay, n. sp.; *Glochiceras* sp.

LOCALITY 46: On trail 3½ miles up Cañón del Orango. Fossils obtained from limestone lenses in carbonaceous shale. Represents beds with *Mazapilites*. Fossils: *Torquatisphinctes*? sp.; *Idoceras*? sp. (small fragment); *Mazapilites zitteli* Burckhardt; *M.* sp.

LOCALITY 51: About a quarter of a mile west of Cañón de la Casita, 400 yards northwest of a big spring and on south flank of an anticline. Fossils occur in limestone concretions near the top of the formation. Collected by R. W. Imlay, September 2, 1935. Includes *Subplanites*? sp. and *Haploceras* sp.

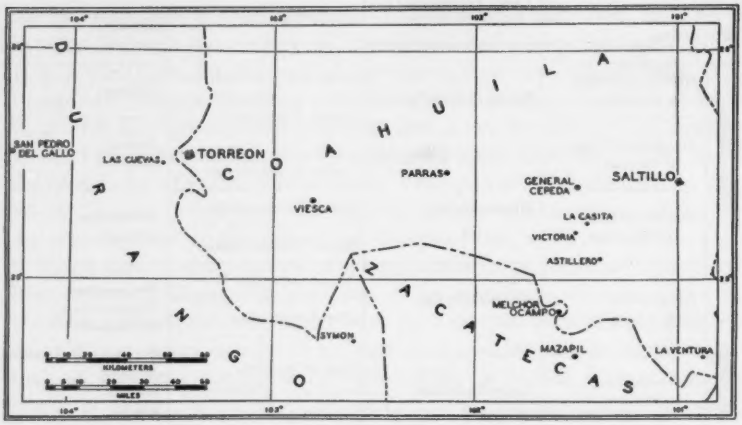


FIGURE 1.—*Index map of fossil localities in north-central Mexico*

LOCALITY 57: About 450 yards east of Cañón de la Casita near the mouth of Cañón del Buey and on south flank of an anticline. Fossils found in limestone concretions about 50 feet below the top of the formation. Represents beds with *Aulacosphinctoides* and *Mazapilites*. Fossils: *Aulacosphinctoides*? sp.; *A. (Subdichotomoceras?)* sp.; *Pachysphinctes*? sp.; *Subdichotomoceras*? sp.; *Torquatisphinctes*? aff. *bangei* Burckhardt; *Haploceras* sp.; *Pseudolissoceras*? sp.; *Aspidoceras* aff. *bispinosum* Quenstedt; *A. casitense* Imlay, n. sp.

LOCALITY 59: Head of short canyon in Sierra San Angel south of Rancho Victoria. Fossils occur in limestone bed in black shale. Represents beds with *Glochiceras fialar*. Fossils: *Glochiceras fialar* (Oppel); *Haploceras costatum* Burckhardt; *H. transatlanticum* Burckhardt; *Involuticeras* aff. *mazapilense* (Burckhardt).

Sierra de Jimulco.—The localities along the south side of Cañón Alamo, about 4 miles southwest of Viesca, Coahuila (Kellum, 1932, fig. 5) are as follows: The section in Cañón Alamo is shown in Figure 3.

LOCALITY K1: On ridge between localities K5 and K2 and a few feet below top of gypsiferous shale. Ammonite horizon contains same fossils

as at K5. Represents beds with *Substeueroceras*. Fossils: *Hildoglochiceras inflatum* Imlay, n. sp.; *H. alamense* Imlay, n. sp.; *Himalayites*? sp.; *Substeueroceras alticostatum* Imlay, n. sp.; *S. kellumi* Imlay, n. sp.; *S. subquadratum* Imlay, n. sp.; *Virgatosphinctes* sp.

Locality K2: On ridge S. 12° W. of Puerto Santiago. Ammonite bed

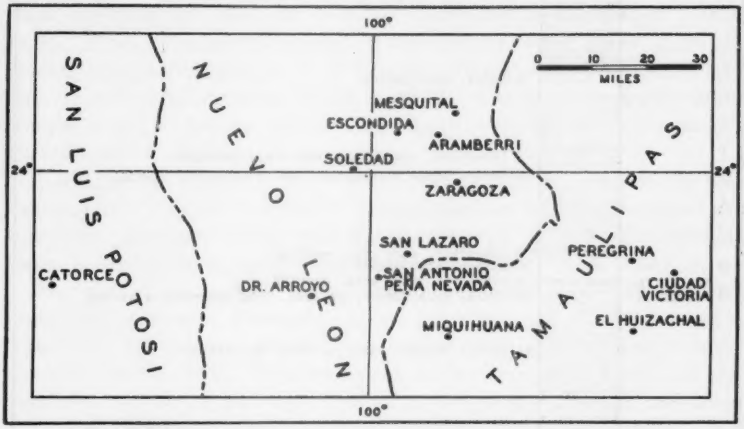


Figure 2.—*Index map of fossil localities in eastern Mexico*

near top of gypsiferous shale but represents same horizon as K4 of the measured section. Represents beds with *Durangites*. Fossils: *Hildoglochiceras grossicostatum* Imlay, n. sp.; *Durangites rarifurcatus* Imlay, n. sp.; *D.* aff. *rarifurcatus* Imlay; *D.* sp.

Locality K3: Section S. 18° W. of Puerto Santiago and 200 feet west of K2. Belemnite from black shale nodule in float on hillside just above ammonite horizon K4 but a little lower stratigraphically.

Locality K4: Section S. 18° W. of Puerto Santiago. Shaly limestone, 20 feet below top of La Casita formation in measured section. Represents beds with *Durangites*. Includes *Durangites* n. sp. ind.

Locality K5: Section S. 18° W. of Puerto Santiago. Red shaly limestone 6 feet from top of La Casita formation in measured section. Beds with *Substeueroceras*. Fossils: *Proniceras* aff. *pronum* (Oppel); *"Aegocrioceras"* sp.; *Aulacosphinctes* sp.; *Berriasella*? sp.; *Hildoglochiceras alamense* Imlay, n. sp.; *Micracanthoceras alamense* Imlay, n. sp.; *M.* n. sp. ind.; *M.* sp.; *M.*? sp.; *Parodontoceras* sp.; *Substeueroceras alticostatum* Imlay, n. sp.; *S. kellumi* Imlay, n. sp.; *S. subquadratum* Imlay, n. sp.; *S.* aff. *subfacciatum* (Steuer).

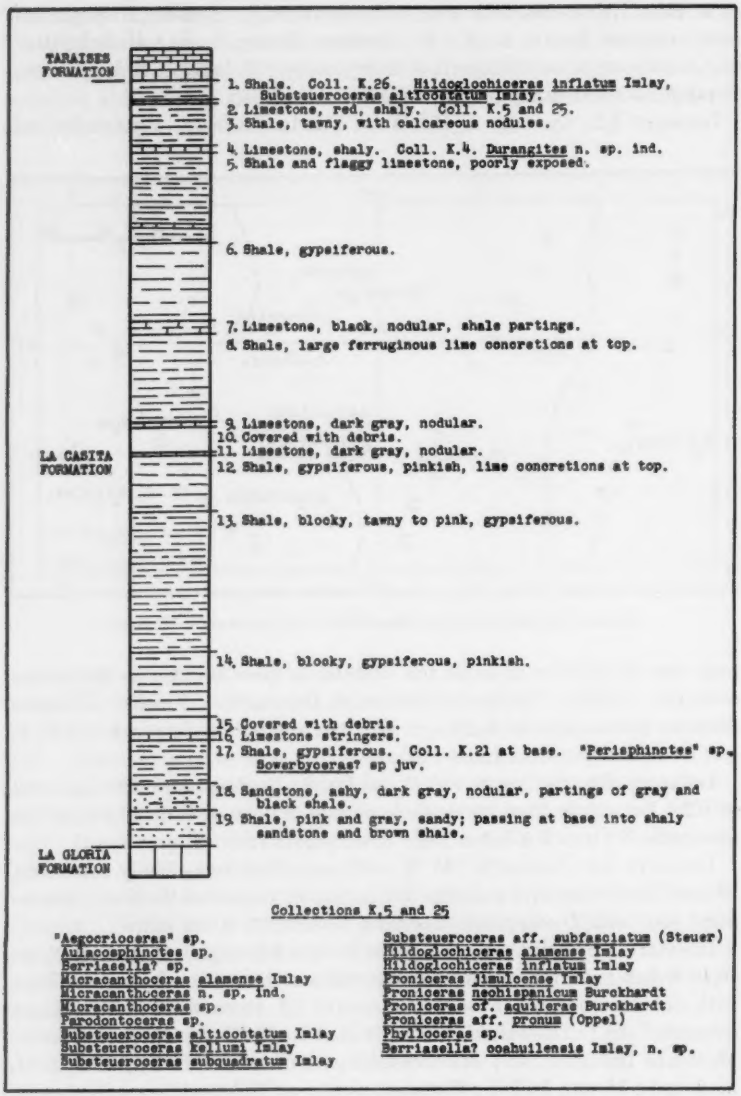

TARAISES FORMATION
1. Shale. Coll. K.26. Hildoglochiceras inflatum Imlay, Substeueroceras alticostatum Imlay.
2. Limestone, red, shaly. Coll. K.5 and 25.
3. Shale, tawny, with calcareous nodules.
4. Limestone, shaly. Coll. K.4. Durangites n. sp. ind.
5. Shale and flaggy limestone, poorly exposed.
6. Shale, gypsiferous.
7. Limestone, black, nodular, shale partings.
8. Shale, large ferruginous lime concretions at top.
9. Limestone, dark gray, nodular.
10. Covered with debris.
LA CASITA FORMATION
11. Limestone, dark gray, nodular.
12. Shale, gypsiferous, pinkish, lime concretions at top.
13. Shale, blocky, tawny to pink, gypsiferous.
14. Shale, blocky, gypsiferous, pinkish.
15. Covered with debris.
16. Limestone stringers.
17. Shale, gypsiferous. Coll. K.21 at base. "Perisphinctes" sp. Sowerbyceras? sp juv.
18. Sandstone, ashy, dark gray, nodular, partings of gray and black shale.
19. Shale, pink and gray, sandy; passing at base into shaly sandstone and brown shale.
LA GLORIA FORMATION
Collections K.5 and 25
"Aegocrioceras" sp.
Aulacosphinctes sp.
Berriasella? sp.
Micracanthoceras alamense Imlay
Micracanthoceras n. sp. ind.
Micracanthoceras sp.
Parodontoceras sp.
Substeueroceras alticostatum Imlay
Substeueroceras kelluni Imlay
Substeueroceras subquadratum Imlay
Substeueroceras aff. subfasciatum (Steuer)
Hildoglochiceras alamense Imlay
Hildoglochiceras inflatum Imlay
Proniceras jimulcense Imlay
Proniceras neohispanicum Burckhardt
Proniceras cf. aguilleras Burckhardt
Proniceras aff. pronum (Oppel)
Phylloceras sp.
Berriasella? coahuilensis Imlay, n. sp.

FIGURE 3.—*Stratigraphic section in Cañón Alamo, Sierra de Jimulco, Coahuila*

Scale 1:50. (For details *see* Imlay, 1938, p. 1683-1684.)

LOCALITY 21: Section S. 18° W. of Puerto Santiago. Ammonites at base of gypsiferous shale. Fossils: *"Perisphinctes"* sp. and *Sowerbyceras*? sp. juv.

LOCALITY 25: Section S. 18° W. of Puerto Santiago. Kellum made collection K5 presumably from the same beds and about 6 to 7 feet stratigraphically below top of La Casita formation. The fossils of the two collections are identical. Fossils: *Hildoglochiceras inflatum* Imlay, n. sp.; *H.* sp. aff. *alamense* Imlay; *Proniceras jimulcense* Imlay, n. sp.; *P. neohispanicum* Burckhardt; *P.* cf. *aguilerae* Burckhardt; *Phylloceras* sp.; *Micracanthoceras alamense* Imlay, n. sp.; *Substeueroceras subquadratum* Imlay, n. sp.; *S. kellumi* Imlay, n. sp.; *S.* aff. *alticostatum* Imlay, n. sp.; *Berriasella*? *coahuilense* Imlay, n. sp.

LOCALITY 26: Section S. 18° W. of Puerto Santiago. Ammonites collected 5 to 8 feet stratigraphically above Collection 25, but the species are identical. Represents beds with *Substeueroceras*. Fossils: *Hildoglochiceras inflatum* Imlay, n. sp.; *Substeueroceras alticostatum* Imlay, n. sp.

Sierra del Chivo.—This name is applied to a range of hills east and northeast of Symón, Durango. About 2½ miles east of Symón rises a prominent hill capped with the Taraises formation and exposing a fairly complete section of La Caja formation on its steep south flank. At the southern base of the hill rises a low ridge composed of Zuloaga limestone. The pass between the hill and ridge is called Cañón del Toboso. The Jurassic section on the north wall of Cañón del Toboso was originally studied by Böse and later restudied by the writer in July, 1936.

The section on the north side of Cañón del Toboso, Sierra del Chivo, near Symón, Durango, measured by R. W. Imlay, from top to bottom, is as follows:

Taraises formation

Unit		Feet
16.	Limestone, at base thin-bedded, nodular, gray. *Thurmannites*? sp. obtained from basal bed (Coll. 1).	

La Caja formation

15.	Shaly limestone, ashy in texture, light gray, poorly exposed. Coll. 2 obtained 18 feet from top contains *Berriasella* sp. Coll. 3 obtained 27½ feet from top contains *Substeueroceras* sp., *Berriasella*? sp., *Berriasella zacatecana* Imlay, n. sp., *Aulacosphinctes*? sp. Coll. 4 obtained 40 feet from top contains *Parodontoceras* sp., and *Parodontoceras* cf. *calistoides* (Behrendsen). Coll. 5 obtained 46 feet from top contains *Proniceras* sp. juv., *P.* cf. *idoceroides* Burckhardt, and *Parodontoceras*	70
14.	Covered. Probably dark gray shale	28
13.	Limestone, dark pinkish gray	1
12.	Shaly limestone, dark gray. *Berriasella* n. sp. ind. (Coll. 6) from middle	2

Unit	Feet
11. Limestone, granular to bladed	1+
10. Shale and shaly limestone, dark gray. Coll. 7, obtained 2 feet from top, contains *Kossmatia* sp.	25
9. Limestone, compact, dark gray	4
8. Limestone, shaly to thin-bedded, dominantly gray but in places pinkish gray. Coll. 8 made 4 feet from top contains *Virgatosphinctes*? aff. *mexicanus* Burckhardt, *Torquatisphinctes* sp., and *"Phylloceras"* sp. Coll. 9 made 22½ feet from top consists of *Mazapilites tobosensis* Burckhardt. Coll. 10 made 25 feet from top contains *Mazapilites* sp. and *Taramelliceras* sp. Coll. 11 made 35½ feet from top contains *Mazapilites symonensis* Burckhardt, *M.* sp., and *Torquatisphinctes* sp. Coll. 12 made 39 feet from top contains *Mazapilites tobosensis* Burckhardt, *Taramelliceras* sp., and *Torquatisphinctes*? cf. *symonensis* Burckhardt. Coll. 13 made 42½ feet from top contains *Mazapilites carinatus* Burckhardt, *M.* sp., and *Torquatisphinctes* sp. Coll. 14 made 45½ feet from top contains *Mazapilites* n. sp. ind. and *Torquatisphinctes* sp. Coll. 15 made 50½ feet from top contains *Mazapilites crassicostatus* Burckhardt, *M. carinatus* Burckhardt, *M. tobosensis* Burckhardt, *M. symonensis* Burckhardt, *M.* n. sp. ind., *"Phylloceras"* sp., *Aulacosphinctoides*? sp., *Taramelliceras* sp., *Torquatisphinctes*? aff. *bangei* Burckhardt, *T.*? aff. *kokeni* Burckhardt., *T.* sp. ind. (many fragments). Coll. 16 made 55½ feet from top consists of *Mazapilites tobosensis* Burckhardt. Coll. 17 made 58 feet from top consists of *Mazapilites* sp.	64
7. Shale, gray. Coll. 18 made from top contains *Mazapilites* sp., *Torquatisphinctes* sp., and *Waagenia* sp.	8½
6. Limestone, pinkish gray	1½
5. Shale mainly, gray; beds of dark gray limestone every few feet	47
4. Limestone, black	1½
3. Shale, gray	3
2. Covered with debris except for a few beds of dark coarse-grained limestone	42
Total	298±

Zuloaga limestone

1. Limestone, thick-bedded, gray, bearing *Nerineas*.

Comparisons of the same section measured by Emil Böse (Burckhardt, 1930, p. 56) are given in Figure 4.

Sierra de Mazapil.—The fossil localities in the vicinity of Mazapil have been indicated by Burckhardt (1906a) on geologic maps by means of asterisks. As these maps may not be readily available to the reader the most important Jurassic localities are listed below with reference to Mazapil.

1. Cañón de San Matias, near Casa Sotelo in Santa Rosa Valley, about 6 miles southeast of Mazapil. Fossil lists by Burckhardt (1906b, p. 154-156; revised 1930, fig. 13a, p. 50).

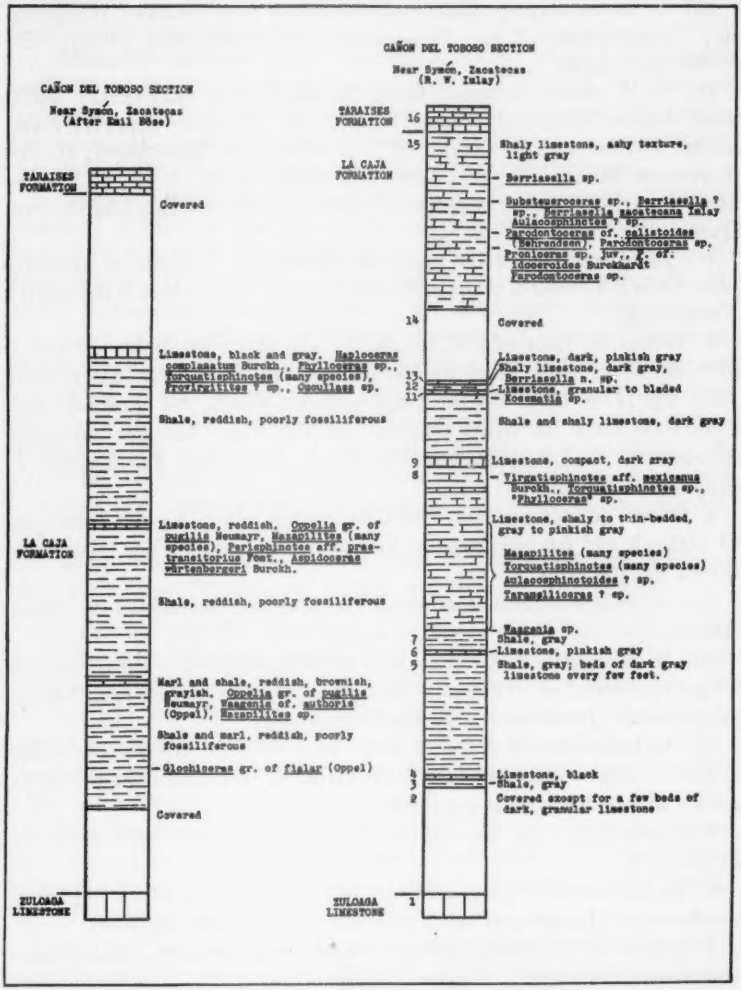


FIGURE 4.—*Stratigraphic section on north side of Cañón del Toboso, Sierra del Chivo* Near Symón, Durango.

2. Puerto Blanco in the Sierra de Santa Rosa is a divide between Cañón de las Bocas and Santa Rosa Valley, about 4 miles southeast of Mazapil. Fossils listed by Burckhardt (1906b, p. 157-159; revised 1930, p. 51). In addition the writer collected the following:

(a) In brown to gray shale with *Waagenia* were obtained *Waagenia* sp.; *Virgatosphinctes*? sp.; *Physodoceras* cf. *avellanoides* Uhlig; *Subdichotomoceras* sp.

(b) In a bed of compact black limestone with *Glochiceras fialar* were obtained *Glochiceras fialar* (Oppel); *G.* aff. *fialar* (Oppel); *Haploceras mexicanum* Burckhardt; *H. transatlanticum* Burckhardt; *H. zacatecanum* Burckhardt; *H. costatum* Burckhardt; *H.* n. sp. aff. *transatlanticum* Burckhardt; *Aspidoceras inflatum binodum* Burckhardt (not Quenstedt); *Taramelliceras* sp.

(c) In brownish shale and marl with *Idoceras* gr. of *balderus* were obtained *Idoceras humboldti* Burckhardt; *Idoceras mexicanum* Burckhardt; *Vermetus* sp.

3. Vereda del Quemado, Sierra de la Caja, about 3½ miles northwest of Mazapil. Fossils listed by Burckhardt (1906b, p. 153-154; revised 1930, fig. 14, p. 52). On the ridge between Vereda del Quemado and Cuesta del Gato the writer obtained the following: *Idoceras canelense* Burckhardt; *I. humboldti* Burckhardt; *I. mexicanum* Burckhardt; *I. neogaeum* Burckhardt.

4. Cuesta de los Colorines, Sierra de la Caja, about 4 miles northwest of Mazapil and 0.6 mile west of Vereda del Quemado. The writer obtained the following fossils:

(a) In beds with *Substeueroceras* was obtained *Berriasella* cf. *oppeli* Kilian.

(b) In beds with *Mazapilites* and *Aulacosphinctoides* were obtained *Virgatosphinctes*? cf. *mexicanus* (Burckhardt); *Phylloceras* sp.; *Oppelia mazapilensis* (Burckhardt); *Pseudolissoceras* sp.

(c) In beds with *Glochiceras fialar* were obtained *Glochiceras fialar* (Oppel); *Haploceras costatum* Burckhardt; *H. transatlanticum* Burckhardt; *H. zacatecanum* Burckhardt.

5. Cuesta de la Caja, Sierra de la Caja, about 5½ miles west-northwest of Mazapil.

6. To the east of Cuesta del Gato, Sierra de la Caja, about 3¼ miles northwest of Mazapil and half a mile east of Vereda del Quemado.

7. Rancho de la Canela, Sierra de Santa Rosa, about 3½ miles south-southwest of Mazapil.

8. Cañón del Aire, Sierra de Santa Rosa, about 2½ miles southwest of Mazapil.

9. Puerto del Aire, a divide between two canyons about 3½ miles southwest of Mazapil and one mile east of locality in Cañón del Aire.

10. Puerto del Chorreadero, Sierra de Santa Rosa, on ridge 4½ miles south-southeast of Mazapil.

Sierras de Zuloaga and Sombreretillo.—Their most important Jurassic fossil localities are as follows:

1. Marls 100 feet from base of La Caja formation about 2 miles south-southeast of Melchor Ocampo just south of crest of the Sierra Zuloaga. Represents beds with *Glochiceras fialar* (Oppel). Fossils: *Glochiceras fialar* (Oppel); *Haploceras* aff. *mexicanum* Burckhardt; *H. transatlanticum* Burckhardt; *H. zacatecanum* Burckhardt; *Involuticeras* sp.

2. Collection made 50 feet from base of the formation about 2 miles northwest of Melchor Ocampo on the east side of Cañón Sombreretillo. Represents beds with *Glochiceras fialar* (Oppel). Fossils: *Glochiceras fialar* (Oppel); *Haploceras costatum* Burckhardt; *H. mexicanum* Burckhardt; *H. transatlanticum* Burckhardt; *H. zacatecanum* Burckhardt.

3. Three miles northeast of Melchor Ocampo in Cañón del Escorpión. Fossils obtained from whitish-gray, platy limestone and black limestone concretions forming upper 25 feet of La Caja formation. Beds with *Substeueroceras*. The specimens of *Proniceras* were obtained from concretions in the lower part of the unit. Fossils: *Parodontoceras* cf. *calistoides* (Behrendsen); *Substeueroceras* sp.; *Proniceras subpronum* Burckhardt; *P. scorpionum* Imlay, n. sp.; *P.* cf. *torresense* Burckhardt; *P.* sp.

4. Todos Santos mine, southern flank of Sierra Zuloaga south of Melchor Ocampo (Burckhardt, 1930, p. 49, 54).

Sierra de la Ventura.—East front of mountain about 6 miles southwest of La Ventura. Fossils obtained from limestone concretions in black shales about 40 feet from base of La Caja formation. Main localities 900 feet and one mile south of Mina de San Francisco. The mine is located in a syncline exposing the basal Taraises formation in its center. About one mile north of the mine the mountain front breaks up into strike ridges and swings from north to northwest.

1. Nine hundred feet south of Mina de San Francisco and 40 feet above base of La Caja formation. Represents beds with *Glochiceras fialar* (Oppel). Fossils: *Glochiceras fialar* (Oppel), *Idoceras tuttlei* Burckhardt, *I.* cf. *balderus* (Loriol).

A few feet higher in the section a limestone concretion yielded many specimens of *Glochiceras fialar* (Oppel), *Haploceras costatum* Burckhardt, *H. felixi* Burckhardt, *H. transatlanticum* Burckhardt, *H. zacatecanum* Burckhardt, *H. mexicanum* Burckhardt.

2. One mile south of Mina de San Francisco on the northern slope of an eastward-trending spur from the main range the beds with *Glochiceras fialar* (Oppel) occur 40 feet above the base of the La Caja formation. Fossils: *Glochiceras fialar* (Oppel), *Idoceras* aff. *soteloi* Burck-

hardt, *Subneumayria ordoñezi* Burckhardt, *Subdichotomoceras*? sp., *Haploceras cornutum* Burckhardt, *H. costatum* Burckhardt, *H.* n. sp. aff. *costatum* Burckhardt, *H. felixi* Burckhardt, *H. mexicanum* Burckhardt, *H. transatlanticum* Burckhardt, *H.* aff. *transatlanticum* Burckhardt, *H. zacatecanum* Burckhardt.

Sierra Madre Oriental.—The most important Jurassic fossil localities are:

1. Bed No. 3 of section on the west flank of the San Lazaro Anticline about 0.6 mile (1 km.) south of the pass on the San Lazaro-Zaragosa trail, Nuevo León (Imlay, 1937b, p. 555). Limestone, argillaceous, finely laminated, gray, black, brownish-black and ashy, containing fossiliferous phosphatic concretions. Represents beds with *Idoceras*. Fossils: *Idoceras* cf. *santarosanum* Burckhardt, *I.* aff. *zacatecanum* Burckhardt.

2. East flank of San Lazaro-Peña Nevada Anticline along strike north of Diablo Cañón, Nuevo León. Fossils from ashy, concretionary, phosphatic shale. Fossils: *Glochiceras diaboli* Imlay, n. sp., *G.* aff. *diaboli* Imlay.

3. Road from La Escondida to Soledad, Nuevo León, 7 miles (11.2 km.) from La Escondida, and 100 yards up small arroyo south of road. Fossils occur in nodular concretions in soft pink bed. Represents beds with *Idoceras*. Fossils: *Idoceras humboldti* Burckhardt; *I. soteloi* Burckhardt; *I. submalleti* Burckhardt; *I. densicostatum* Imlay, n. sp.; *I.* cf. *densicostatum* Imlay, n. sp.; *I.* aff. *striatum* Imlay, n. sp.; *I.* sp.; *Involuticeras* sp. juv. aff. *mazapilense* (Burckhardt); *Nebrodites* n. sp. aff. *N. doublieri* (D'Orbigny); *Ochetoceras* sp.; *Sutneria* aff. *cyclodorsatus* (Moesch); *Taramelliceras* aff. *nereus* Fontannes; *Glochiceras fialar* (Oppel); *Haploceras transatlanticum* Burckhardt; *H. zacatecanum* Burckhardt.

4. Near San Lazaro the Jurassic section is complicated and difficult to determine. (See Figure 5.) Much clearer and probably similar is the Mesquital section (Fig. 6) concerning which Burckhardt (1930, p. 85) incorrectly stated that the Cretaceous limestones rest directly on the red beds.

Bed No. 3 of section on west bank of Arroyo San Lazaro (Imlay, 1937b, p. 557) opposite a spring at the mouth of Cañón Tijera, about a mile north of Rancho San Lazaro, Nuevo León. Most of the Jurassic fossils from this locality are not especially designated as occurring in bed No. 3 and are merely labeled Cañón San Lazaro. Fossils occur in blue-gray, thin-bedded, phosphatic limestone which is interbedded with ashy marls. Represents beds with *Idoceras*. Fossils: *Idoceras soteloi* Burckhardt; *I. viverosi* Burckhardt; *I. zacatecanum* Burckhardt; *I. sanlazarense* Imlay, n. sp.; *I. involutum* Imlay, n. sp.; *I. striatum* Imlay, n. sp.; *I. tamau-*

lipanum Imlay, n. sp.; *I. balderus* (Oppel) Burckhardt; *Ochetoceras sanlazarense* Imlay, n. sp.; *Subneumayria* aff. *ordoñezi* (Burckhardt); *Involuticeras* sp. juv. aff. *mazapilense* (Burckhardt); *Rasenia profulgens* Burckhardt.

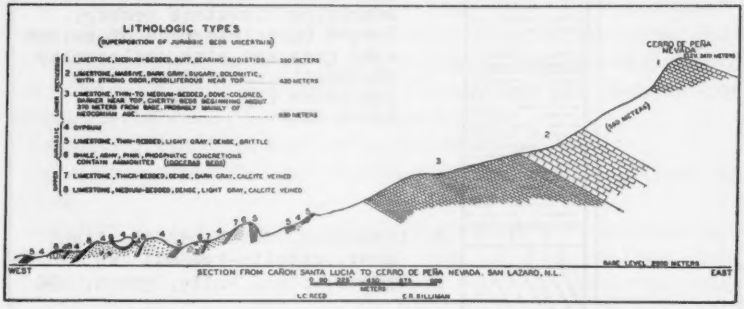


FIGURE 5.—*Structure section from Cañón Santa Lucia to Cerro de Peña, Nevada* Near San Lazaro, Nuevo León.

Mountains west of Laguna district.—The most important Jurassic fossil localities are:

LOCALITY A-16. Cañón Maravillas, about 2¼ miles southwest of Las Cuevas Ranch (Kellum, 1936, p. 1056, 1066, pl. 13), Durango, Mexico. Fossils occur in dark gray, nodular limestone 580 feet above the base of unit D. Probably represents the middle Oxfordian. Fossils: *Indosphinctes*? (several species), *Subgrossouvria*? sp., *Pseudopeltoceras*? sp.

San Pedro del Gallo.—Burckhardt collected fossils at a number of localities which he designated on the geologic map by means of numbers (Burckhardt, 1910, pl. XLIX). At localities 4, 5, 11, 16, 22, 23, the fossils occur in black limestone concretions in gray to black shale and marl. The stratigraphy has been discussed by Burckhardt (1910, p. 309-321, pl. XLIX; 1912, p. 203-226; 1930, p. 59-61, figs. 20, 21). The writer visited the locality in 1936 and made the collections listed below.

LOCALITY 4: About 2 miles north-northwest of village at side of road to Mapimí. Probably represents only upper part of beds with *Idoceras*. Fossils: *Idoceras complanatum* Burckhardt; *I. johnsoni* Burckhardt; *I. lorioli* Burckhardt; *I. sauteri* Burckhardt; *I.* aff. *neohispanicum* Burckhardt; *I.* aff. *tuttlei* Burckhardt; *Nebrodites haizmanni* Burckhardt; *N.* sp.; *Sutneria* aff. *cyclodorsatus* Moesch; *Phylloceras* cf. *subplicatius* Burckhardt, *Physodoceras* sp.; *Streblites complanatus* Burckhardt; *S.*

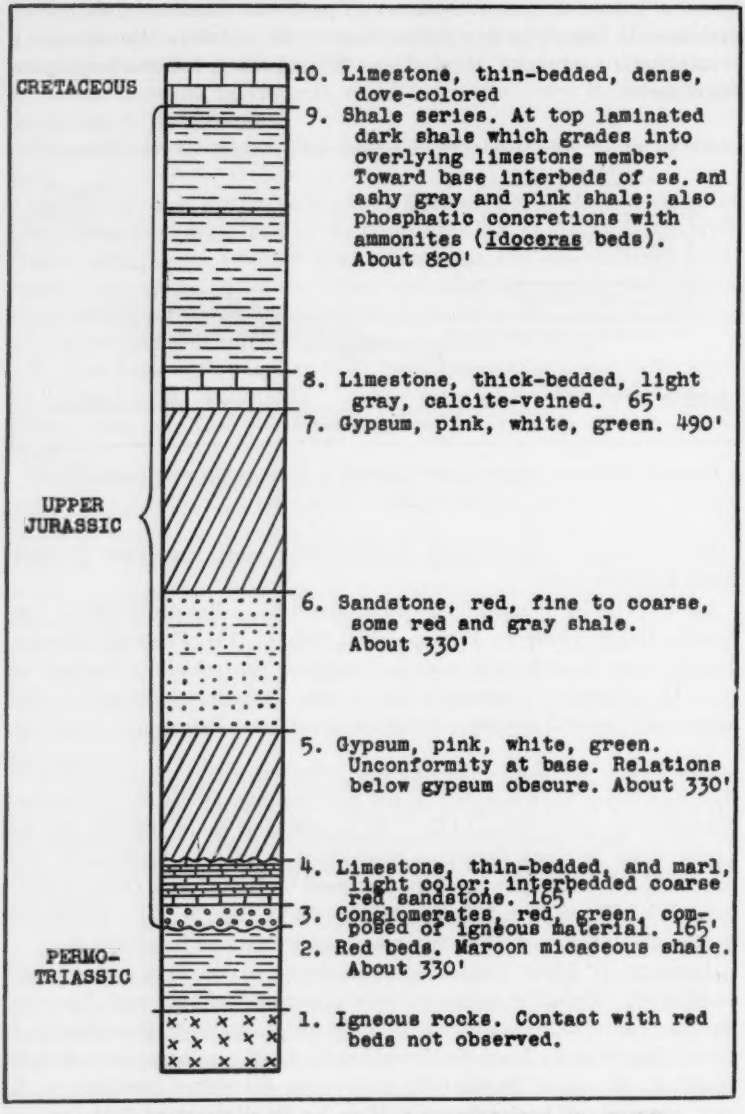

CRETACEOUS
UPPER JURASSIC
PERMO-TRIASSIC
10. Limestone, thin-bedded, dense, dove-colored
9. Shale series. At top laminated dark shale which grades into overlying limestone member. Toward base interbeds of ss. and ashy gray and pink shale; also phosphatic concretions with ammonites (Idoceras beds). About 820'
8. Limestone, thick-bedded, light gray, calcite-veined. 65'
7. Gypsum, pink, white, green. 490'
6. Sandstone, red, fine to coarse, some red and gray shale. About 330'
5. Gypsum, pink, white, green. Unconformity at base. Relations below gypsum obscure. About 330'
4. Limestone, thin-bedded, and marl, light color; interbedded coarse red sandstone. 165'
3. Conglomerates, red, green, composed of igneous material. 165'
2. Red beds. Maroon micaceous shale. About 330'
1. Igneous rocks. Contact with red beds not observed.

FIGURE 6.—*Stratigraphic section on northwest flank of Barrier Anticline*

On north side of Rio Blanco, near Mesquital, Nuevo León. (Measured by L. C. Reed and E. R. Silliman; checked by C. L. Baker.) Not published previously.

serratus Burckhardt; *S. uhligi* Burckhardt; *Sowerbyceras inflatum* Burckhardt; *Subplanites*? sp.

LOCALITY 5: About 2¾ miles north of village at side of road to Mapimí. Represents beds with *Idoceras*. Fossils: *Idoceras disciforme*? Burckhardt; *I.* aff. *dedalus* (Gemmellaro) Burckhardt; *I. lorioli* Burckhardt; *I.* aff. *mutabile* Burckhardt; *I.* aff. *tuttlei* Burckhardt; *Nebrodites burckhardti* Imlay, n. sp.; *N.* sp.; *Taramelliceras* aff. *nereus* Fontannes; *Sutneria* aff. *cyclodorsatus* Moesch; *Aspidoceras* aff. *longispinum* Sowerby; *Phylloceras subplicatius* Burckhardt; *Physodoceras* sp.; *Sowerbyceras inflatum* Burckhardt; *Streblites* sp., *Virgatites*? sp.

LOCALITY 6: Small hill south of Rancho de las Lagunitas.

LOCALITY 8: One mile north of village at northern base of Cerro del Volcán.

LOCALITY 10: About 1½ miles northeast of village at southeastern edge of Cerro del Volcán above Locality 11. Red and green marl and shale alternating with gray limestone. Probably represents upper Oxfordian. Fossils: *Ochetoceras mexicanum* Burckhardt; *O.* sp.; *"Perisphinctes" lagunitasensis* Burckhardt; *"P."* aff. *virgulatus* Quenstedt; *"P."* (many fragments).

LOCALITY 11: About 1⅓ miles northeast of village at southeastern base of Cerro del Volcán. Represents beds with *Idoceras*. Fossils: *Glochiceras fialar* (Oppel); *G. angustiumbilicatum* Imlay, n. sp.; *Haploceras*? sp.; *Idoceras aguilerae* Burckhardt; *I. complanatum* Burckhardt; *I.* aff. *cragini* Burckhardt; *I.* aff. *dedalum* (Gemmellaro) Burckhardt; *I.* cf. *durangense* Burckhardt; *I. lorioli* Burckhardt; *I. sauteri* Burckhardt; *I.* cf. *mutabile* Burckhardt; *Nebrodites*? sp.; *N. nodosocostatus* Burckhardt; *Ochetoceras* cf. *neohispanicum* Burckhardt; *Sutneria* aff. *cyclodorsatus* Moesch; *Taramelliceras* aff. *nereus* Fontannes; *Aspidoceras bispinosoides* Burckhardt; *A.* aff. *bispinosum* Quenstedt; *A.* cf. *longispinum* Sowerby; *Physodoceras* aff. *americanum* (Burckhardt); *P.* cf. *laevigatum* (Burckhardt); *Sowerbyceras inflatum* Burckhardt; *Streblites* sp.; *Phylloceras* aff. *consanguinum* Gemmellaro; *P. recticulatum* Burckhardt.

Some fossils were collected by native helpers supposedly from locality 11 but probably from the northeastern part of Cerro de la Cruz as they are probably of Tithonian age. Considering the strong deformation at San Pedro del Gallo, it is not improbable that a lense of Tithonian age has been pushed into beds of Kimmeridgian age. Fossils: *Micracanthoceras* n. sp. aff. *koellikeri* (Oppel); *M.* cf. *microcanthum* (Oppel); *M. aguajitense* Imlay, n. sp.; *M. acanthellum* Imlay, n. sp.; *M.* sp.; *Spiticeras uhligi* Burckhardt.

LOCALITY 12: About 0.9 mile north of village at southern base of Cerro del Volcán. Represents beds with *Idoceras*. Fossils: *Idoceras* aff. *du-*

rangense Burckhardt; *I.* sp.; *I. durangense* Burckhardt; *Sutneria* aff. *cyclodorsatus* Moesch; *Nebrodites flexuosus* Burckhardt; *Aspidoceras* aff. *longispinum* Sowerby; *A.* sp.; *Physodoceras pavlowi* (Burckhardt); *Sowerbyceras inflatum* Burckhardt; *Streblites* sp.; *Subplanites*? sp.; *Pachysphinctes*? sp.

LOCALITY 15: Immediately west of village at east side of Cerro del Panteón. Gray argillaceous shale, in places yellowish or reddish. Represents beds with *Substeueroceras.*

LOCALITY 16: At southern edge of village near Tanque. Represents beds with *Idoceras.* Fossils: *Idoceras durangense* Burckhardt; *I.* aff. *tuttlei* Burckhardt; *I.* sp.; *I.* n. sp. ind.; *Nebrodites* aff. *agrigentinus* Burckhardt; *Sutneria* aff. *cyclodorsatus* Moesch; *Taramelliceras* aff. *nereus Fontannes; Streblites* aff. *durangensis* Burckhardt.

LOCALITY 22: About 0.5 mile east of village.

LOCALITY 23: About 0.6 mile southeast of village to the north of Cerro de Las Liebres.

LOCALITY 24: About one mile east of village near Arroyo Aquajito.

LOCALITY 25: About 2 miles southeast of village at west base of La Sierrita.

To Burckhardt's localities the writer adds the following:

LOCALITY a: Unnamed beds transitional from Jurassic to Lower Cretaceous (mapped by Burckhardt as Lower Cretaceous). Fossils occur in thin-bedded limestone which is mainly gray but in part reddish. Near center of low hill, Cerro del Panteón, about 1,000 feet west of San Pedro del Gallo and 150 feet northwest of graveyard. Beds are stratigraphically slightly higher than the *Substeueroceras* beds of Burckhardt's Locality 15 but are probably of Jurassic age. Fossils: *Aulacosphinctes*? sp.; *Phylloceras*? sp.; *Thurmannites* sp.; *Simoceras* sp.

LOCALITY b: About a quarter of a mile east of southeast corner of Cerro del Volcán on road nearest hill. Black shale and marl with limestone concretions. *Nebrodites crassicostatus* Burckhardt.

STATE OF PRESERVATION

Many of the Upper Jurassic fossils were obtained from phosphatic limestone concretions of which most are dark gray or black in the interior and coated with iron oxide on the surface. The fossils found in the concretions are excellently preserved and have not been distorted by the compressive forces to which the surrounding shales and marls have been subjected. A few of the shells, especially the body chamber, have been partly crushed, probably before burial. The association of concretions and fossils is apparently accidental as most of the concretions do not

contain fossils. For example, at San Pedro del Gallo, only about one concretion in a hundred contained fossils. Commonly, however, a number of fossils are found in a single concretion.

A second type of preservation is represented by the beds with *Glochiceras* in the Sierra de la Ventura. Here some limestone beds of varying hardness weather into large spheroidal masses. The fossils are mainly distorted internal molds.

A third type of preservation is represented by the beds in Cañón Alamo of the Sierra de Jimulco where the fossils occur as integral parts of the limestones and marls, retain part of their shells, and have been more or less distorted by earth movements.

External molds, usually crushed and distorted, are common in the Portlandian and Tithonian beds. Genera can usually be recognized from these molds, but specific identifications are difficult.

BIOLOGICAL ANALYSIS

In Tables 3-8 are listed the ammonites described by Burckhardt and the writer from north-central Mexico and from the San Lazaro region of eastern Mexico. These include about 300 species distributed as shown in Table 2.

TABLE 2.—*Distribution of ammonites*

Stage	Subdivision	Number of species
Tithonian	*Substeueroceras* and *Proniceras*	56
Portlandian	*Durangites* and *Kossmatia*	33
Upper Kimmeridgian	*Torquatisphinctes* and *Mazapilites*	48
Middle Kimmeridgian	*Waagenia*	10
	Glochiceras gr. of *fialar* (Oppel) and *Idoceras* gr. of *durangense* Burckhardt	80
Lower Kimmeridgian	*Idoceras* gr. of *balderus* (Oppel)	49
Upper Oxfordian	*Dichotomosphinctes*	20
Middle Oxfordian	*Indosphinctes*?	3

In this paper are described 53 species, nearly all of which are new. Those represented only by external molds or fragmentary specimens have not been described unless they were of special paleontological or stratigraphical interest. No varieties of forms which are already well represented have been described. Many genera, especially the perisphinctids, show great variation, and it would be possible to increase the number of species or varieties manifold from a purely taxonomic viewpoint. However, the writer believes that the purposes of stratigraphy and paleontology are better served at present by allowing a certain degree of latitude in the definition of species which belong to rapidly evolving groups.

The affinities of the Upper Jurassic faunas of Mexico are predominantly with the faunas of the Mediterranean province and to a lesser extent with the Andean and Indian provinces. These relationships have been discussed by Burckhardt (1930, p. 105-114) whose conclusions have lately been evaluated by Spath (1933, p. 879-880).

The Phylloceratidae are poorly represented, but specimens have been found at many horizons. The Oppelidae comprise five genera which occur in many beds from the upper Oxfordian to the lower Portlandian but, with the exception of *Streblites,* are represented by few specimens. The Haploceratidae comprise five genera which are well represented by species and individuals. *Glochiceras* and *Haploceras* are abundant in the middle Kimmeridgian. *Pseudolissoceras* characterizes the boundary beds of the Kimmeridgian and Portlandian. *Mazapilites* is common in the upper Kimmeridgian. *Hildoglochiceras* occurs in the upper Portlandian and Tithonian.

The Perisphinctidae comprise about 17 genera but with the exception of *Idoceras* and *Torquatisphinctes* are poorly represented in numbers and species. This is due in part to failure in finding deposits favorable for their burial and preservation. After all, the deposits of the Mexican Geosyncline have been very briefly studied.

The Virgatitidae are poorly represented by a few specimens and probably include the genera *Epivirgatites* and *Provirgatites. Subneumayria* and *Epicephalites* may belong in this family.

The Berriasellidae are well represented by 10 genera and many species. In Mexico *Durangites* and *Kossmatia* are restricted to the Portlandian; *Micracanthoceras* occurs in both the Portlandian and Tithonian; *Substeueroceras, Aulacosphinctes, Berriasella,* and *Parodontoceras* are common in the Tithonian. *Himalayites* and *Thurmannites* occur rarely in the highest Tithonian.

The Olcostephanidae are represented only by *Proniceras* which appears to range from late Portlandian to late Tithonian. The Aspidoceratidae are represented in considerable numbers by *Aspidoceras, Physodoceras,*

and *Nebrodites*. *Waagenia* is rather uncommon. *Simoceras* and *Pseudopeltoceras* are probably present.

CORRELATION

Middle Oxfordian.—Fossils of this age have been found only in eastern Durango about 2¼ miles southwest of Las Cuevas. Many fragments have been provisionally assigned to the genera *Subgrossouvria, Indosphinctes,* and *Pseudopeltoceras.*

Upper Oxfordian.—The only described ammonites of this age are from San Pedro del Gallo, Durango, and are listed in Table 3 of this report. The dominant genus is *Dichotomosphinctes,* which is represented by at least six species, but the genera *Prososphinctes, Otosphinctes,* and *Biplices* are probably present. The forms which Burckhardt (1912, p. 35) referred to *Perisphinctes* group of *virgulatus* Quenstedt are possibly closer to *Dichotomosphinctes* than to *Lithacoceras.*

Lower Kimmeridgian.—The lower Kimmeridgian is richly fossiliferous and is dominated by *Idoceras* group of *balderus* (Oppel). (See Table 4.) Other characteristic forms are *Nebrodites* cf. *doublieri* (D'Orbigny), *N. aguilerae* (Burckhardt), *Rasenia profulgens* (Burckhardt), *Subneumayria ordoñezi* (Burckhardt), *Metahaploceras* aff. *nereus* (Fontannes), *Epicephalites epigonus* (Burckhardt), *Aspidoceras* cf. *acanthicum* Loriol, *Aspidoceras* (many species), *Pararasenia zacatecana* (Burckhardt).

Middle Kimmeridgian.—The lower part of the middle Kimmeridgian is characterized by *Idoceras* group of *durangense* Burckhardt and by *Glochiceras* group of *fialar* (Oppel). (See Table 5); the upper part is characterized by *Waagenia* and *Physodoceras.* At San Pedro del Gallo, Durango, many species of *Idoceras* group of *durangense* occur at the same localities as *Glochiceras* group of *fialar,* but the conditions of collecting are such that their occurrence in the same beds is somewhat uncertain. However, in the Sierra de la Ventura of southeastern Coahuila *Idoceras tuttlei* Burckhardt and *I.* cf. *balderus* (Oppel) were found associated with *Glochiceras fialar* (Oppel) in the same bed. Although the two groups of *Idoceras,* distinguished by Burckhardt, almost certainly overlap in time, the evidence to date indicates that the group of *durangense* is slightly younger. The forms commonly associated with *Glochiceras fialar* (Oppel) are *Haploceras* of the *zacatecanum-mexicanum* group and *Involuticeras.* The forms commonly associated with *Idoceras durangense* Burckhardt are *Nebrodites, Streblites, Aspidoceras, Sowerbyceras,* and *Metahaploceras.* It appears, therefore, that two fairly distinct faunal assemblages existed simultaneously in the lower part of the middle Kimmeridgian; that associated with *Glochiceras fialar* has much the wider

distribution. However, the distinctness of these faunas may be more apparent than real as local conditions of burial might explain the abundance of certain forms at San Pedro del Gallo and their scarcity in other areas.

The genus *Waagenia* has been found in Mexico only in the north-central part and in the highest beds of the middle Kimmeridgian. (See Table 6.) In the region of Mazapil, Zacatecas, it is associated with *Physodoceras avellanoides* Burckhardt (not Uhlig). In Cañón del Toboso, near Symón, Durango, *Waagenia* occurs in the same bed with the lowest *Mazapilites* and *Torquatisphinctes* found in the section. In Cañón de la Casita in the Sierra de Parras, *Waagenia* occurs with *Torquatisphinctes*? aff. *diversecostatus* (Burckhardt) and *Subdichotomoceras*? sp.

Upper Kimmeridgian.—The beds placed here were considered by Burckhardt (1930, Table 6, p. 68, 69) as Portlandian and were divided into the *Aulacosphinctes* beds above and the *Mazapilites* beds below. Spath (1931, p. 465, 466) pointed out that many of the perisphinctids from the upper beds greatly resemble the Kimmeridgian genus, *Torquatisphinctes* and that the presence of *Mazapilites* and *Aspidoceras* indicates a Kimmeridgian rather than a lower Portlandian age (1933, p. 796). Spath at one time (1931, p. 466, 482, 484) referred many of Burckhardt's species of the *Aulacosphinctes (Perisphinctes) bangei* group to *Torquatisphinctes* but apparently decided later (1933, p. 865) that these species were closer to *Aulacosphinctoides* which occurs in the upper Kimmeridgian and lower Portlandian (Spath, 1933, p. 850). The writer remeasured the section in Cañón del Toboso, near Symón, Durango, and found that the genera *Torquatisphinctes*? and *Mazapilites* occur together throughout a considerable thickness of strata. Both *Torquatisphinctes* and *Aulacosphinctoides* appear to be represented, if these genera are interpreted in the broad sense. As a consequence of the association of these genera the beds have been renamed. (See Table 7.) In the Cañón del Toboso section, the stratigraphically lowest *Mazapilites* occurs with *Waagenia*, and the stratigraphically highest *Mazapilites* is overlain by a bed containing *Virgatosphinctes* and *Torquatisphinctes*?. The former genus indicates a Portlandian age for the bed in question.

Portlandian.—This stage is represented by the beds with *Durangites* and *Kossmatia* (Table 8) and probably by the upper part of the beds with *Torquatisphinctes*?. The most common genera are *Kossmatia*, *Durangites*, *Micracanthoceras*, and *Hildoglochiceras*. *Grayiceras* and *Virgatosphinctes* are poorly represented, but this may be due to failure in collecting. *Kossmatia* has been found at many places in northern and eastern Mexico. The genus *Durangites* has been found at two localities in southern Coahuila associated with *Hildoglochiceras*, and at San Pedro

del Gallo (Burckhardt, 1912, p. 143, 205) associated with *Kossmatia* and *Micracanthoceras*. One other association of *Durangites* with *Kossmatia* from Mexico has been reported by Burckhardt (1930, p. 91-93) at the gorge of Totolapa to the north of Huauchinango, Puebla. The occurrence of *Micracanthoceras* below the Tithonian is not unprecedented as it is reported from the upper Portlandian of Madagascar (Besaire, 1936, p. 66). The presence of *Hildoglochiceras* is interesting as the genus is characteristic of the Portlandian faunas of India (Spath, 1928, p. 154, 159-161) and Madagascar (Besaire, 1936, p. 51, 53, 65).

Tithonian.—Beds of this age in Mexico have yielded a large fauna dominated by the Berriasellidae. (See Table 9.) The genus *Substeueroceras*, judging from the occurrences recorded by Burckhardt (1930), ranges from the Portlandian to the end of the Tithonian but is most abundant in latest Tithonian. Some of the species are similar to Argentine species which Gerth (1925, p. 128) places in the Berriasian (Infra-Valanginian). But the association of the Mexican species with *Micracanthoceras, Hildoglochiceras, Aulacosphinctes, Virgatosphinctes,* and *Proniceras* definitely places their age as Tithonian. The occurrence of *Hildoglochiceras* in the Tithonian is noteworthy as it has not been recorded previously from beds younger than the Portlandian. *Berriasella* and *Parodontoceras* are represented by species considered more characteristic of the Tithonian than of the Berriasian. *Proniceras* is well represented and is associated with *Substeueroceras* in the Sierra de Jimulco and the Sierra de Sombreretillo. Burckhardt (1930, Table 6, p. 63) apparently erred in placing *Proniceras* stratigraphically below *Kossmatia,* as the writer found it above *Kossmatia* in the Cañón del Toboso section, near Symón, Durango. An examination of Burckhardt's writings shows that he had no certain stratigraphic basis for placing *Proniceras* below *Kossmatia.* At San Pedro del Gallo he found *Proniceras* in a small outcrop surrounded by alluvium (Burckhardt, 1912, p. 205; 1930, p. 63). Because this outcrop lies between beds with *Durangites* to the east and beds with *Idoceras* to the west, Burckhardt assumed it was of lower Portlandian age. To the writer this assumption seems risky in view of the intense deformation which has occurred in the region of San Pedro del Gallo. Burckhardt (1930, p. 54) likewise recorded *Proniceras* from the highest unit of the Jurassic section in the Sierra Zuloaga but did not mention finding *Kossmatia* or *Substeueroceras* in the section. In the Sierra Ramirez, Burckhardt (1930, p. 57) depended on the field work of Böse who found a bed with *Proniceras* and *Aulacosphinctes* below beds with *Substeueroceras* and above beds with *Mazapilites.* However, this occurrence does not show the stratigraphic position of *Proni-*

ceras with respect to *Kossmatia*. The present work definitely shows that in Mexico *Proniceras* occurs in younger beds than *Kossmatia* and has about the same range as *Substeueroceras*.

SYSTEMATIC DESCRIPTIONS

Genus *Phylloceras* Suess 1865

"Phylloceras" sp.

(Plate 2, figures 1-4)

DESCRIPTION: Two specimens represent a species which perhaps belongs to the genus *Ptychophylloceras* Spath (1927, p. 41). Form discoidal, moderately stout; whorls ovate in section, a little higher than wide, strongly embracing; flanks and venter evenly convex; umbilicus very narrow and fairly deep.

The outer whorl of the figured specimen is sutured to its anterior end. It is marked by five shallow constrictions which are strongest near the umbilicus and on the venter. The constrictions trend nearly radially for a few millimeters near the umbilicus, then curve strongly forward on the lower part of the flanks, recurve slightly on the upper part of the flanks, and cross the venter transversely. The constrictions are bounded on the venter by faint swellings. No indications of ribs or striae are visible.

Dimensions in mm. are as follows:

Specimen	Diameter	Whorl height	Whorl thickness	Umbilical width
19289	55	31	28	2.5
19199	29	16.5	15	..

OCCURRENCE: La Caja formation (*Torquatisphinctes* and *Mazapilites* beds). Bed 8, collection 8 of Imlay's section on north side of Cañón del Toboso, Sierrita del Chivo, near Symón, Durango.

Genus *Ochetoceras* Haug 1885

Ochetoceras sanlazarense Imlay, n. sp.

(Plate 1, figures 1-4)

DESCRIPTION: Shell fairly large for genus, flattened, discoidal; outer whorl wedge-shape in section, much higher than wide, embracing preceding whorl four-fifths, thickest at edge of umbilicus; flanks feebly convex, sloping gently to acutely sharpened venter which does not bear lateral carinae. Umbilicus narrow; wall moderately high, nearly vertical, separated from flanks by a feeble carina. Anterior third of outer whorl represents incomplete body chamber.

Shell ornamented by a spiral groove, by broadly triangular, flared flank ribs, and by bundles of coarse striae on the venter. The spiral groove is narrow, is situated slightly below the middle of the flanks, is distinct at the posterior end of outer whorl and indistinct at the anterior end. The flanks below the spiral groove are marked by broad, irregularly spaced ribs of two sizes which begin at edge of umbilical wall and incline slightly forward. The larger ribs are separated by one or rarely two smaller ribs. The flanks above the spiral groove are marked by strong, broad, widely spaced ribs which are concave forward. Most of them are the continuations of the larger ribs below the spiral groove. On the venter of the posterior half of the outer whorl, these flank ribs become small and sharp and are separated by two

TABLE 3.—*Oxfordian ammonites*

	Oxfordian ammonites	San Pedro del Gallo: Cerro Volcan Southeast (Locality 10) Lower Beds	San Pedro del Gallo: Cerro Volcan Southeast (Locality 10) Upper Beds	San Pedro del Gallo: Cerro Volcan South Upper beds	San Pedro del Gallo: Lagunitas	Villa Juarez Uplift: Collection A16
Upper Oxfordian	*Taramelliceras crassicostatum* (Burckhardt)	X				
	" *pichleriformis* (Burckhardt)	X	X			
	" *neohispanicum* (Burckhardt)		X			
	Ochetoceras canaliculatum var. *burckhardti* O'Connell		X			
	" *mexicanum* Burckhardt		X			
	" *pedroanum* Burckhardt		X			
	Dichotomosphinctes aff. *plicatiloides* O'Connell	X				
	" cf. *plicatilis* (De Riaz) Burckhardt	X				
	" *wartaeformis* (Burckhardt)	X				
	" cf. *chloroolithicus* (Nikitin) Burckhardt	X				
	" *elisabethaeformis* (Burckhardt)	X				
	" cf. *alterneplicatus* (Waagen) Burckhardt	X				
	Prososphinctes trichoplocoides (Burckhardt)	X				
	Otosphinctes? cf. *rota* (Sinzow) Burckhardt	X				
	" cf. *promiscuus* (Burckhardt) Burckhardt	X				
	Biplices? *durangensis* (Burckhardt)	X				
	" *lagunitasensis* (Burckhardt)				X	
	Lithacoceras? *virgulatus* (Quenstedt) Burckhardt		X			
	" cf. *lucingense* (Choffat) Burckhardt			X		
	Aspidoceras sp. juv. gr. of *perarmatum* (Sowerby)			X		
Middle Oxfordian	*Indosphinctes*? sp.					X
	Subgrossouvria? sp.					X
	Pseudopeltoceras? sp.					X

TABLE 4.—*Ammonites of beds with Idoceras group of balderus (Oppel)*

Beds with *Idoceras* gr. of *balderus* (Oppel)	Sierra de la Caja: Vereda del Quemado	Sierra de la Caja: Cuesta de los Colorines	Sierra de la Caja: Cuesta de la Caja	Sierra de Santa Rosa: Cañón de San Matias near Casa Solelo	Sierra de Santa Rosa: Puerto Blanco	Sierra de Santa Rosa: Puerto del Chorreadero	Sierra de Santa Rosa: Rancho de la Canela	San Lazaro Region: Between Escondida and Soledad	San Lazaro Region: San Lazaro Canyon	San Lazaro Region: West flank of San Lazaro Anticline
Lytoceras sp. ind.	X									
Rasenia profulgens (Burckhardt)				X						
Subneumayria ordoñezi (Burckhardt)				X	X					
" aff. *ordoñezi* (Burckhardt)									X	
Oppelia boesei (Burckhardt)	X									
Metahaploceras aff. *nereus* (Fontannes)					X			X		
Taramelliceras harpoceroides (Burckhardt)					X					
" *flexuosa costata* (Quenstedt)				X						
Epicephalites epigonus (Burckhardt)					X					
Sutneria aff. *cyclodorsatus* (Moesch)	X				X			X		
Subdichotomoceras McLachlani (Burckhardt)				X						
Nebrodites agusterae (Burckhardt)				X						
" cf. *doublieri* (D'Orbigny)				X						
" n. sp. aff. *doublieri* (D'Orbigny)								X		
Aspidoceras cf. *acanthicum* Loriol				X						
" *quemadense* Burckhardt	X									
" *contemporaneum* Favre		X								
" *bispinosum* Quenstedt	X									
" *mazapilense* Burckhardt	X									
" *euomphaloides* Burckhardt				X						
Idoceras zacatecanum Burckhardt	X		X	X					X	
" aff. *zacatecanum* Burckhardt										X
" *humboldti* Burckhardt	X			X	X			X		
" *submalleti* Burckhardt						X		X		
" cf. *hoepei* (Neumayr)	X									
" *lazevolutum* (Fontannes)	X									
" *canelense* Burckhardt	X									
" *neogaeum* Burckhardt	X						X			
" *soteloi* Burckhardt				X				X	X	
" *mexicanum* Burckhardt	X				X		X			
" cf. *balderus* (Loriol)				X						
" *balderus* (Oppel)				X					X	
" *santarosanum* Burckhardt				X						
" aff. *santarosanum* Burckhardt										X
" *figueroae* Burckhardt				X						
" *viverosi* Burckhardt				X					X	
" *subdedalus* Burckhardt				X						
" *cajense* Burckhardt	X									
" *inflatum* Burckhardt	X									
" *sanlazarense* Imlay, n. sp.									X	
" *involutum* Imlay, n. sp.									X	
" *striatum* Imlay, n. sp.									X	
" aff. *striatum* Imlay, n. sp.								X		
" *tamaulipanum* Imlay, n. sp.									X	
" *densicostatum* Imlay, n. sp.								X		
Pararasenia zacatecana (Burckhardt)				X						
" sp.	X									
Involuticeras sp. aff. *mazapilense* (Burckhardt)								X	X	
Ochetoceras sanlazarense Imlay, n. sp.									X	

TABLE 5.—*Ammonites of beds with Glochiceras group of fialar (Oppel) and Idoceras group of durangense Burckhardt*

	toria	Sierra de la Caja	Sierra de Santa Rosa	Melchor Ocampo area			San Lazaro region	San Pedro del Gallo

TABLE 6.—*Ammonites of b*

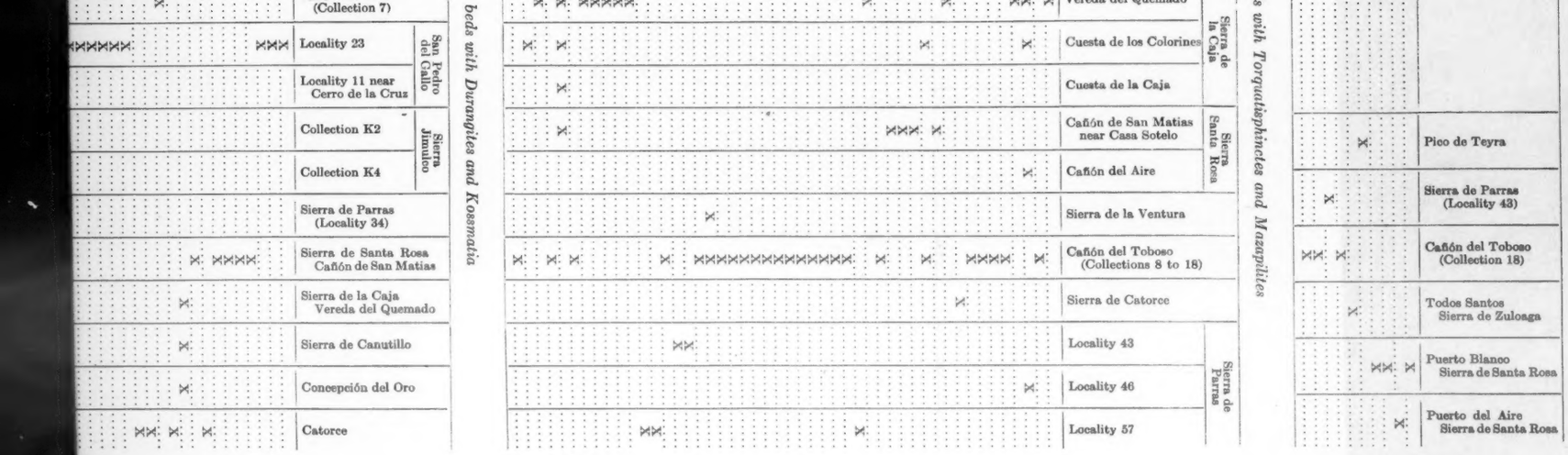
Beds with *Waagenia*	
Physodoceras avellanoides Burckhardt (not Uhlig)	
Waagenia cf. *beckeri* (Neumayr)	
" cf. *harpephora* (Fontannes)	
" cf. *knopi* (Neumayr)	
" cf. *hybonota* (Oppel)	
" sp.	
" cf. *authoris* (Oppel)	
" *parrasensis* Imlay, n. sp.	
Mazapilites sp.	
Torquatisphinctes? sp.	

TABLE 7.—*Ammonites of beds with Tor*

Beds with *Torquatisphinctes* and *Mazapilites*	Sierra de la Caja: Vereda del Quemado	Sierra de la Caja: Cuesta de los Colorines
Phylloceras apenninicum Canavari	X	
"*Phylloceras*" sp.		
Mazapilites zitteli Burckhardt	X	X
" *fissilobatus* Burckhardt	X	
" *symonensis* Burckhardt		
" *crassicostatus* Burckhardt		
" *tobosensis* Burckhardt		
" *carinatus* Burckhardt		
" *mexicanus* (Castillo and Aguilera)		
Virgatosphinctes aguileri (Burckhardt)	X	
" *mexicanus* (Burckhardt)		
" aff. *mexicanus* (Burckhardt)		X
" sp. ind.		
Subplanites cf. *danubiensis* (Schlosser)		
" sp.		
Provirgatites? sp.		
Epivirgatites? sp. (=*P. nikitini* in Burckhardt)	X	
Pachysphinctes? sp.		
Torquatisphinctes? *tobosensis* (Burckhardt)		
" *theodosii* (Burckhardt)		
" *alexeii* (Burckhardt)		
" *pervinguieri* (Burckhardt)		
" aff. *colubrinus* (Toucas)		
" *corona* (Burckhardt)		
" *filan* (Burckhardt)		
" *boesei* (Burckhardt)		
" *neohispanicus* (Burckhardt)		
" *bangei* (Burckhardt)		
" *symonensis* (Burckhardt)		
" *diversecostatus* (Burckhardt)		
" cf. *kokeni* (Behrendsen)		
" *subbleicheri* (Burckhardt)		
" aff. *diversecostatus* (Burckhardt)		
Aulacosphinctoides? (*Subdichotomoceras*?) sp.		
" sp.		
Aspidoceras casilense Imlay		
" aff. *bispinosum* (Quenstedt)		
Physodoceras cyclotum (Oppel) Steuer	X	
" *phosphoricum* (Burckhardt)	X	
" *cajense* (Burckhardt)	X	
" *falax* (Burckhardt)	X	
" *zacatecanum* (Burckhardt)	X	
" *würtenbergeri* (Burckhardt)		
Oppelia mazapilensis (Burckhardt)	X	X
Taramelliceras cf. *pupilis* (Neumayr)		
Pseudolissoceras subrasile (Burckhardt)	X	
" sp.		X
Haploceras complanatum (Burckhardt)		

TABLE 8.—*Ammonites of beds with D*

Beds with *Durangites* and *Kossmatia*	Cañón del Toboso (Collection 7)	San Pedro del Gallo: Locality 23	San Pedro del Gallo: Locality 11 near
Grayiceras mexicanus (Burckhardt)		X	
Kossmatia interrupta Burckhardt		X	
" *pectinata* Burckhardt		X	
" *victoris* (Burckhardt)			
" *burkarti* (Burckhardt)			
" aff. *victoris* (Burckhardt)			
" cf. *victoris* (Burckhardt)			
" *flexicostata* (Castillo and Aguilera)			
" *zacatecana* Burckhardt			
" cf. *richteri* (Oppel)			
" *potosina* Burckhardt			
" sp.	X		
" *alamitosensis* (Castillo and Aguilera)			
" *lenki* (Castillo and Aguilera)			
Durangites acanthicus Burckhardt		X	
" *incertus* Burckhardt		X	
" *vulgaris* Burckhardt		X	
" *humboldti* Burckhardt		X	
" *nodulatus* Burckhardt		X	
" *intercalatus* Burckhardt			


(Collection 7)
Locality 23
San Pedro del Gallo
Locality 11 near Cerro de la Cruz
Collection K2
Sierra Jimulco
Collection K4
Sierra de Parras (Locality 34)
Sierra de Santa Rosa Cañón de San Matias
Sierra de la Caja Vereda del Quemado
Sierra de Canutillo
Concepción del Oro
Catorce
beds with Durangites and Kossmatia
Vereda del Quemado
Sierra de la Caja
Cuesta de los Colorines
Cuesta de la Caja
Cañón de San Matias near Casa Sotelo
Sierra Santa Rosa
Cañón del Aire
Sierra de la Ventura
Cañón del Toboso (Collections 8 to 18)
Sierra de Catorce
Locality 43
Locality 46
Locality 57
Sierra de Parras
beds with Torquatisphinctes and Mazapilites
Pico de Teyra
Sierra de Parras (Locality 43)
Cañón del Toboso (Collection 18)
Todos Santos Sierra de Zuloaga
Puerto Blanco Sierra de Santa Rosa
Puerto del Aire Sierra de Santa Rosa
beds with Waagenia

...psis of the Upper Jurassic ammonite fauna of northern and eastern Mexico

	Sierra de Parras Middle Part, southern Coahuila	Sierra de Jimulco Cañón Alamo, southwest Coahuila	San Pedro del Gallo, Durango	San Lazaro Region, Nuevo León	Mountains West of Laguna District Villa Juares Uplift, Durango
...lay, n. sp. (Behrendsen), ...hardt, *P.* sp. ...rdt)		*Substeueroceras alticostatum* Imlay, *S. kellumi* Imlay, *S. subquadratum* Imlay, *S.* aff. *subfasciatum* (Steuer) *Aulacosphinctes* sp. *Berriasella? coahuilensis* Imlay, *Berriasella?* sp. *Parodontoceras* sp. *Micracanthoceras alamense* Imlay, *M.* n. sp. ind. *Himalayites?* sp. *Virgatosphinctes* sp. *Hildoglochiceras alamense* Imlay, *H. inflatum* Imlay "*Aegocrioceras*" sp. *Proniceras jimulcense* Imlay, *P. neohispanicum* Burckhardt, *P.* aff. *pronum* (Oppel)	*Aulacosphinctes?* sp. *Thurmanniles* sp. *Simoceras* sp. *Substeueroceras* cf. *koeneni* (Steuer), *S. lamellicostatum* Burckhardt, *S. durangense* Burckhardt *Berriasella tenuicostata* Burckhardt *Micracantheceras* gr. of *koellikeri* (Oppel) *Aulacosphinctes* n. sp. *Proniceras* sp. juv. aff. *pronum* (Oppel) *Aulacosphinctes* sp.		*Proniceras?* sp.
	Durangites astillerensis Imlay, *D.* cf. *acanthicus* Burckhardt, *D.* sp. *Hildoglochiceras grossicostatum* Imlay, *H. ecarinatum* Imlay	*Durangites rarifurcatus* Imlay, *D.* n. sp. ind., *D.* sp. *Hildoglochiceras grossicostatum* Imlay	*Grayiceras mexicanus* Burckhardt *Kossmatia interrupta* Burckhardt, *K. pectinata* Burckhardt *Micracantheceras* cf. *microcanthum* (Oppel) *Durangites* (9 species) *Aucella* gr. *of mosquensis* Keys *Micracanthoceras aguajitense* Imlay, *M. acanthellum* Imlay		*Kossmatia?* sp.
(Burckhardt) ...eumayr)	(Locality 57) *Aulacosphinctoides?* sp. *Subdichotomoceras?* sp. *Pachysphinctes?* sp. *Aspidoceras castense* Imlay, *A.* aff. *bispinosum* Quenstedt *Torquatisphinctes?* aff. *bangei* Burckhardt *Pseudolissoceras?* sp. *Haploceras* sp. (Locality 46) *Torquatisphinctes?* sp. *Mazapilites villeti* Burckhardt *Idoceras?* sp. (Locality 43) *Aulacosphinctoides?* (*Subdichotomoceras?*) sp., *A.?* aff. *diversecostatus* Burckhardt *Waagenia parrasensis* Imlay *Glochiceras* sp.				
	Glochiceras fialar (Oppel) *Haploceras costatum* Burckhardt, *H. transatlanticum* Burckhardt *Involuticeras* aff. *mazapilense* (Burckhardt)		*Glochiceras fialar* (Oppel) *Sowerbyceras* (2 species) *Ochetoceras neohispanicum* Burckhardt *Strebites* (12 species) *Aspidoceras* gr. *bispinosum* (4 species) *A.* gr. *durangense* (2 species), *A.* gr. *acanthicum* (4 species) *Nebrodites* (9 species) *Idoceras* gr. *durangense* (13 species) *I.* gr. *balderus* (2 species) *Sutneria* aff. *cyclodorsatus* (Moesch) *Phylloceras* (2 species)	*Glochiceras fialar* (Oppel), *G. diaboli* Imlay *Haploceras transatlanticum* Burckhardt, *H. zacatecanum* Burckhardt *Idoceras humboldti* Burckhardt, *I. soteloi* Burckhardt, *I. sub-malleti* Burckhardt, *I. densicostatum* Imlay, *I. viverosi* Burckhardt, *I. zacatecanum* Burckhardt, *I. sanlasarense* Imlay, *I. involutum* Imlay, *I. striatum* Imlay, *I. tamaulipanum* Imlay *Involuticeras* aff. *mazapilense* Burckhardt *Subneumayria* aff. *ordoñezi* Burckhardt *Ochetoceras sanlasarense* Imlay *Nebrodites* aff. *doublieri* D'Orbigny *Sutneria* aff. *cyclodorsatus* Moesch *Metahaploceras* aff. *nereus* Fontannes	
	Belemnites, brachiopods, and pelecypods		*Prososphinctes trichoplocoides* (Burckhardt) *Lithacoceras? virgulatus* (Quenstedt) Burckhardt, *L.?* cf. *lucingense* (Choffat) Burckhardt *Ochetoceras* (3 species) *Biplices?* (2 species) *Taramelliceras* (3 species) *Dichotomosphinctes* (6 species) *Otosphinctes?* (2 species)		
					Indosphinctes? sp. *Subgrossouvria?* sp. *Pseudopeltoceras?* sp.

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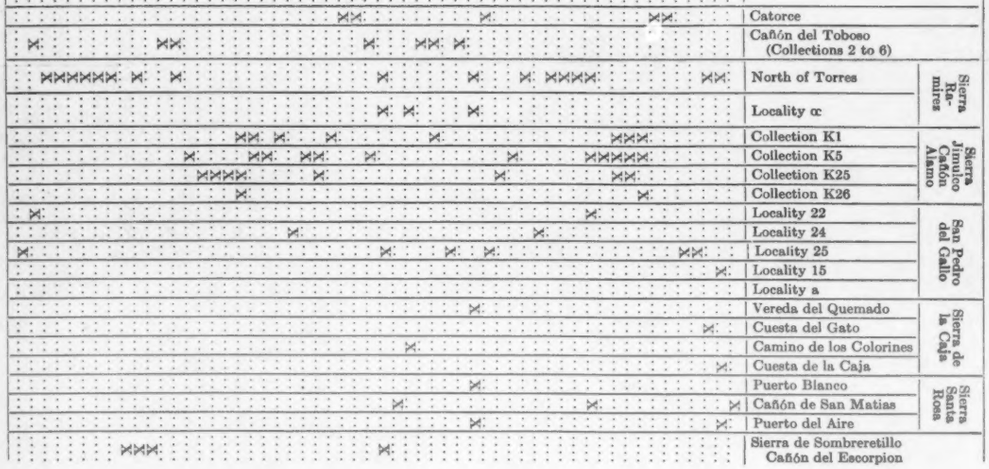
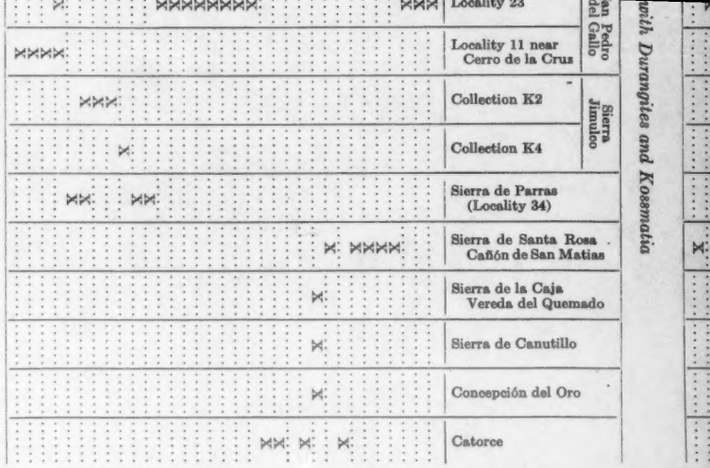


Proniceras with Substeueroceras and Proniceras



Durangites with Durangites and Kossmatia

TABLE 10.—*Synopsis of the Upper Jurassic ammonite fauna of northern and e*

	Subdivisions (After L. F. Spath, 1933, Tables I and II)		Sierra de la Ventura Southeastern Coahuila	Sierras de la Caja and Santa Rosa near Masapil, Zacatecas	Sierra de Symón	Sierra de Parras Middle Part, southern Coahuila	Cañón A
TITHONIAN	*Substeueroceras* and *Proniceras* beds	*Micracanthoceras* and *Hildoglochiceras*		*Berriasella* gr. of *calisto* (D'Orbigny) *Substeueroceras* cf. *koenen*i (Steuer) S. ct. permulticostatus (Steuer)	*Berriasella* sp. *B. sacatecana* Imlay, n. sp. *Substeueroceras* sp. *Aulacosphinctes*? sp. *Parodontoceras* cf. *calistoides* (Behrendsen), *P.* sp. *Proniceras* cf. *idoceroides* Burckhardt, *P.* sp. juv. cf. *subpronum* (Burckhardt) *Berriasella* n. sp. ind.		*Substeueroceras* Imlay, *S.* *subfasciatum* *Aulacosphinct* *Berriasella*? *c* sp. *Parodontocera* *Micracanthoce* ind. *Himalayites*? *Virgatosphinc* *Hildoglochicer* *flatum* Imla "*Aegocriocera* *Proniceras ji* *cum* Burck
PORTLANDIAN	*Durangites* and *Kossmatia* beds			*Steueroceras santarosanum* Burckhardt (at top) *Kossmatia victorie* Burckhardt, *K. burkarti* Burckhardt, *K. sacatecana* Burckhardt	*Kossmatia* sp.	*Durangites astillerensis* Imlay, *D.* cf. *acanthicus* Burckhardt, *D.* sp. *Hildoglochiceras grossicostatum* Imlay, *H. ecarinatum* Imlay	*Durangites ra* *D.* sp. *Hildoglochice*
UPPER KIMMERIDGIAN	*Torquatisphinctes* and *Masapilites* beds		*Torquatisphinctes*? cf. *kokeni* (Behrendsen)	*Virgatosphinctes*? *mexicanus* (Burckhardt) *Pseudolissoceras subrasile* (Burckhardt) *Subdichotomoceras* sp. *Subplanites* cf. *danubiensis* (Schlosser) *Masapilites sitteli* Burckhardt *Masapilites fissilobatus* Burckhardt *Physodoceras cyclotum* (Oppel) Steuer *Phylloceras apenninicum* Canavari *Epivirgatites*? cf. *nikitini* (Michalski)	*Virgatosphinctes*? aff. *mexicanus* (Burckhardt) "*Phylloceras*" sp. *Torquatisphinctes* sp. (top bed) *Torquatisphinctes* (many species) *Masapilites* (many species) *Taramelliceras* gr. of *pugilis* (Neumayr) *Aulacosphinctoides*? sp.	(Locality 57) *Aulacosphinctoides*? sp. *Subdichotomoceras*? sp. *Pachysphinctes*? sp. *Aspidoceras casitense* Imlay, *A.* aff. *bispinosum* Quenstedt *Torquatisphinctes*? aff. *bangei* Burckhardt *Pseudolissoceras*? sp. *Haploceras* sp. (Locality 46) *Torquatisphinctes*? sp. *Masapilites sitteli* Burckhardt *Idoceras*? sp. (Locality 43) *Aulacosphinctoides*? (*Subdichotomoceras*?) sp., *A.*? aff. *diversecostatus* Burckhardt *Waagenia parrasensis* Imlay *Glochiceras* sp.	
LOWER AND MIDDLE KIMMERIDGIAN	*Waagenia* beds			*Waagenia* cf. *beckeri* (Neumayr) *Waagenia* cf. *harpephora* (Neumayr) *Waagenia* cf. *knopi* Neumayr *Physodoceras avellanoides* Burckhardt (not Uhlig)	*Waagenia* sp. *Masapilites* sp. *Torquatisphinctes* sp.		
	Idoceras beds: *Glochiceras* gr. of *fialar* (Oppel) and *Idoceras* gr. of *durangense* Burckhardt		*Glochiceras fialar* (Oppel) *Haploceras* (many species) *Subneumayria ordoñesi* Burckhardt *Idoceras* aff. *soteloi* Burckhardt *Subdichotomoceras*? sp.	*Glochiceras fialar* (Oppel) *Haploceras* (5 species) *Taramelliceras* (3 species) *Involuticeras praecursor* Burckhardt, *I. masapilense* Burckhardt *Phylloceras* aff. *consanguineum* Gemmellaro *Aucella* gr. of *pallasi* Keys	*Glochiceras* gr. of *fialar* (Oppel)	*Glochiceras fialar* (Oppel) *Haploceras costatum* Burckhardt, *H. transatlanticum* Burckhardt *Involuticeras* aff. *masapilense* (Burckhardt)	
	Idoceras beds: *Idoceras* gr. of *balderus* (Oppel)			*Idoceras* (14 species) *Nebrodites aguileras* Burckhardt, *N.* cf. *doublieri* (D'Orbigny) *Aspidoceras bispinosum* (Zittel) Quenstedt, *A.* (many species) *Suineria* aff. *cyclodorsatus* (Moesch) *Oppelia boesei* Burckhardt *Metahaploceras* aff. *nereus* Fontannes *Taramelliceras harpoceroides* Burckhardt, *T. flexuosa costata* Quenstedt *Epicephalites epigonus* Burckhardt			
OXFORDIAN	Upper					Belemnites, brachiopods, and pelecypods	
	Middle						

to six short ribs equally sharp and inclined forward. On the venter of the anterior half of the outer whorl the flank ribs disappear, and concomitantly the short ribs on the venter develop into bundles of coarse striae. The ornamentation of the shell becomes much finer anteriorly, and at the extreme anterior end the entire flanks are marked by faint striae.

Greatest diameter of holotype 95 mm.; width of umbilicus 12 mm.; height of last whorl 51 mm.; thickness of last whorl 21 mm.

REMARKS: *Ochetoceras sanlazarense* Imlay differs from *O. neohispanicum* Burckhardt (1912, p. 46, pl. X, figs. 1-3, 7) by its stronger, more distantly spaced ribs. Among foreign species *O. canaliferum* (Oppel) (1863, p. 195, pl. LII, figs. 4 a, b) is similar but has a slightly higher and thinner whorl section, fewer flank ribs, and at a comparable size has much finer ribbing. *O. zio* (Oppel) (1863, p. 196, pl. LII, figs. 7 a-c) has closer-spaced main ribs ventral to the spiral groove. Also, the fine ribs between the main ribs are larger than in *O. sanlazarense* Imlay and bifurcate instead of forming striae. *O. palissyanum* (Fontannes) (1879, p. 48, pl. V, fig. 6) has a wider umbilicus, a wider groove, and finer ornamentation on the flanks.

TYPE: Holotype 19531, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Idoceras* zone). San Lazaro Canyon, Nuevo León.

Genus *Glochiceras* Hyatt 1900

Glochiceras diaboli Imlay, n. sp.

(Plate 6, figures 8-10)

DESCRIPTION: The species is represented definitely by six specimens of which the holotype is the largest. A fragment of an outer whorl of a large ammonite (Pl. 4, fig. 10) probably also belongs to the species.

Shell discoid, flattened; whorls subrectangular in section, slightly higher than wide, embracing about two-fifths, with greatest thickness at the middle of the flanks; venter regularly convex on inner whorls, slightly flattened on outer whorl; flanks slightly convex, rounding rather abruptly into venter on outer whorls, passing gradually into umbilical wall. Umbilicus fairly large, moderate in depth; wall steeply inclined.

The ornamentation consists of spiral furrow, fine falciform striae, and falciform folds. The spiral furrow is situated a little below the middle of the flanks, begins at a diameter of about 17 mm., and is never very pronounced. The striae start at the suture and curve forward on the lower part of the flanks to the spiral furrow where they describe a sharp fold which is convex forward.

On the flanks above the spiral furrow, the striae describe a broad curve which is convex backward, and on the venter form a deep fold which is convex forward. The falciform folds begin at a diameter of about 10 mm., are fairly regularly spaced, occur only above the spiral furrow, and are curved like striae which cover them. Anteriorly they become broader, stronger, and more widely spaced. They are strongest on the upper part of the flanks but diminish rapidly in strength and are scarcely visible on the venter. The largest specimens bear faint spiral markings on the venter. The suture line is unknown.

Greatest diameter of holotype 36 mm.; width of umbilicus 9.3 mm.; height of last whorl 15.4 mm.; thickness of last whorl 12 mm.

REMARKS: This species is distinguished from *G. fialar* (Oppel), as figured by Burckhardt (1906b, p. 77, pl. 19, figs, 1-19, pl. 20, figs, 1-6, 12, 14, 15) by more

vigorous ornamentation on the flanks, weaker ornamentation on the venter, less pronounced spiral furrow, broader venter, and subrectangular whorl section.

TYPE: Holotype 18998; paratypes 18999, 19000, Museum of Paleontology, University of Michigan.

OCCURRENCE: Concretionary, ashy, phosphatic shale on east flank of San Lazaro-Peña Nevada Anticline along strike north of Diablo Canyon, Nuevo León.

Glochiceras fialar Burckhardt (not Oppel)

REMARKS: There is a reasonable doubt as to whether the Mexican forms described by Burckhardt (1906, p. 77, pl. XIX, figs. 1-19; pl. XX, figs. 1-6, 12, 14, 15) are the same as *G. fialar* (Oppel), and the matter will probably have to be settled by European students as the published figures of the type are inadequate. Burckhardt has pointed out the considerable variation in shape and ornamentation of the Mexican forms. This variation is well shown by about 200 specimens in the University of Michigan collections. Much of the variation in shape is due to post-humous deformation, and some of the apparent difference in ornamentation is due to the condition of preservation. Certain specimens could be described as varieties, but this seems inadvisable as all the forms are connected by many transitions and the species is limited to a fairly narrow horizon. If varieties were found in other horizons, there would be some use in giving them special names. The species probably is the most common and widely distributed of any in the Upper Jurassic of Mexico.

SPECIMENS: 19524, 18957, 18992, 18980, 18974, 19542, 19001, 18967, Museum of Paleontology, University of Michigan.

OCCURRENCE: Many localities in north-central Mexico, especially in the Sierras Sombreretillo, Zuloaga, de la Caja, Santa Rosa, de la Ventura, de Parras, and Catorce. Also found at San Pedro del Gallo, Durango (Locality 11 of Burckhardt); and 7 miles (11.2 km.) from La Escondida on road to Soledad, Nueva León.

Glochiceras augustiumbilicatum Imlay, n. sp.

(Plate 7, figures 4-6)

DESCRIPTION: Form small, discoidal; outer whorl elongate-ovate in section, much higher than wide, embracing about two-thirds; flanks nearly flat; venter evenly rounded. Umbilicus narrow; wall low, vertical, rounded rather abruptly into flanks. The outer whorl appears to represent a nearly complete body chamber.

Shell ornamented with fine, falciform striae which begin at the line of involution, curve forward on the lower part of the flank, form a pronounced forwardly inclined sinus in the spiral groove, describe a curve convex to the rear on the upper part of the flanks, and then recurve to form a forwardly inclined sinus on the venter. The striae become a little stronger ventrally, and on the venter develop into broad but extremely low ribs. Some of the striae are slightly reinforced on passing the spiral groove. The spiral groove is situated slightly below the middle of the flanks and on the anterior three-fourths of the outer whorl. The upper part of the flanks and the venter bear many faint, spiral markings. On the left side of the type is a short groove directly above the edge of the umbilicus. The short groove is probably due to an injury as a similar groove is not present on the right side. The suture line is unknown.

Greatest diameter of holotype 39 mm.; width of umbilicus 6.5 mm.; height of last whorl 19.5 mm.; thickness of last whorl 11 mm.

REMARKS: This species is characterized by its narrow umbilicus and flattened form. In these respects it resembles *Haploceras mexicanum* Burckhardt (1906b, p. 89, pl. 23, figs. 9-15) which, however, enlarges more rapidly and has different ornamentation. *Glochiceras fialar* (Oppel) and *G. diaboli* Imlay, n. sp. are more evolute, have more inflated whorl-sections, and stronger ornamentation.

TYPE: Holotype 18581, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Idoceras* beds): *Burckhardt's* locality 11, about 1⅓ miles (2¼ km.) northeast of San Pedro del Gallo, Durango.

Genus *Hildoglochiceras* Spath 1924

Hildoglochiceras grossicostatum Imlay, n. sp.

(Plate 2, figures 5-11; Plate 3, figures 1-7, 9-11)

DESCRIPTION: The species is represented by about 100 specimens of which the majority are internal molds of immature forms.

Shell small, discoidal; whorls ovate in section, higher than wide, thickest near or slightly below middle of flanks, embracing about three-fourths; flanks gently convex, becoming broader and flatter during growth, rounding evenly into venter, sloping toward umbilicus at a low angle; venter evenly rounded on immature forms, becoming narrower during growth and developing a keel. Umbilicus fairly narrow, moderate in depth; wall extremely low and nearly vertical, separated from flanks by a faint carina. Aperture unknown.

The innermost whorls are smooth. The outer whorls are marked by a prominent, narrowly rounded keel, by strongly sickle-like ribs and striae, and by a moderately developed spiral groove. The relative strength of these various features and the stage of development at which they appear vary somewhat in different individuals, but the order of development is always the same, i.e. keel, ribs, and then spiral groove. A faint sharpening of the venter is visible at a diameter of about 4 mm. and develops anteriorly into a true keel at a diameter of about 10 mm. On the outer whorl the keel is high, strong, rounded, and slightly uneven. Sickle-like striae are barely visible at a diameter of about 7 mm., at which size they curve forward from the line of involution to the lower third of the flanks, then backward to the upper third of the flanks, then forward again to the sharpened venter where they meet striae from the opposite flanks at a sharp angle. At this diameter the striae are only slightly stronger on the upper part of the flanks than on the lower part. During development the striae on the flanks persist as the stems of sickles, but their points of maximum forward inflection become higher and on the outer whorls are slightly below the middle of the flanks. At diameters varying from 10 to 14 mm. some of the striae on the upper part of the flanks become grouped in bundles which develop into high, sharp, falcoid ribs, between which are the terminations of other striae. The ribs approach the keel at a sharp angle, some merge with the keel, and others barely flatten out before reaching it.

The spiral groove appears at a diameter of about 14 mm. or a little later and is bounded dorsally by a faint ridge or swelling which persists into the adult whorls. The maximum inflection of the striae takes place in the lower part of the groove. On the outer whorls the groove is fairly broad but shallow.

The suture line can be traced fairly accurately on only one form (Paratype 20028) at a diameter of 12.3 mm. Probably due to immaturity of the form, its suture line is much simpler than those of the Indian forms that have been figured (Uhlig, 1903, p. 20, fig. 4; pl. 3, fig. 5; Uhlig, 1910, pl. LVIII, figs. 4d, 5d; Spath, 1928, pl. XIX,

figs. 5, 6; pl. XIII, fig. 17; Spath, 1931, pl. XCIX, fig. 6). The external lobe is shorter than the first lateral and is divided by a broad secondary saddle. The first lateral lobe is fairly broad and is deeper than the second lateral. The saddles are bifid. The external and first lateral saddles are broad, the first lateral saddle is a little higher than the external saddle, and its two parts are unequal, the inner being higher than the outer. An interesting peculiarity of the suture line is its asymmetry. The median saddle of the external lobe lies to the right of the mid-line of the venter.

Dimensions in mm. of several specimens are as follows:

Specimen	Greatest diameter	Whorl height	Whorl thickness	Umbilical width
holotype 20020	...	18.0	12.0	..
paratype 20026	23.5	11.7	7.0	3.7
paratype 20022	24.5	13.0	8.0	3.5
paratype 20024	24.0	11.5	8.0	3.7
paratype 20027	18.7	9.8	7.0	3.4
paratype 20021	20.0	10.8	..	3.1
paratype 20025	15.5	7.5	6.0	3.0
paratype 20028	16.3	7.6	5.3	3.0

REMARKS: *Hildoglochiceras grossicostatum* Imlay is characterized by its coarse ribbing, pronounced keel, and small umbilicus. *H. propinquum* (Waagen) (1875, p. 45, pl. XI, figs. 4a, b; Spath, 1931, pl. LXXXVI, figs. 1a, b) and *H. dieneri* (Uhlig) (1903, p. 19, pl. VII, figs. 9a, b) resemble the Mexican form but are less involute and are less coarsely ornamented. *H. colei* Spath (1931, pl. XCIX, fig. 6; pl. LXVIII, fig. 8, pl. LXXXI, figs. 4a, b, pl. LXXXII, fig. 4) approaches the Mexican form even more but is a little less involute, the spiral groove is probably less developed, and the ribs appear to approach the venter at a less sharp angle.

TYPE: Holotype 20020; paratypes 20021, 20022, 20023, 20024, 20025, 20026, 20027, 20028, 20029, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Durangites* beds), (1) Locality 34 in the Sierra de Parras, Coahuila. (2) Locality K 2 in Cañón Alamo, Sierra de Jimulco, Coahuila.

Hildoglochiceras ecarinatum Imlay, n. sp.

(Plate 5, figures 1-4)

DESCRIPTION: This species is represented by two immature forms. Shell small, discoidal; whorls ovate in section, higher than wide, thickest slightly above middle of flanks, embracing about three-fourths; flanks gently convex, rounding evenly into venter, sloping toward umbilicus at a low angle; venter narrowly rounded but not sharpened. Umbilicus fairly narrow, moderate in depth; wall extremely low and nearly vertical, separated from flanks by a faint carina. Aperture unknown.

The ornamentation consists of striae on the lower two-thirds of the flanks, of ribs on the upper parts of the flanks and the venter, and of a faint spiral groove which is bounded dorsally by a faint spiral ridge. The striae and ribs form sickles as in *H. grossicostatum* Imlay. The striae begin at the line of involution, incline slightly forward on the umbilical wall, curve slightly backward on the lower fourth of the flanks, are strongly inflected forward just above the middle of the flanks along a zone marking a faint spiral ridge, and are then inflected backward on the upper part of the flanks where they pass into ribs. The ribs arise at the place

of maximum backward inflection and then curve strongly forward to the venter where they form a narrow arch with the ribs from the opposite side. The ribs are strongest on the venter, but there is no evidence of a keel or of ventral tubercles. The ventral ribbing is strongest to the right of the mid-line, which may indicate a slight degree of asymmetry of the shell. At the extreme anterior end of the holotype is an intercalary rib which is restricted to the venter. Faint striae are visible on and between some ribs. The spiral ridge near the middle of the flanks is faint at the posterior end of both types. It becomes broader anteriorly and on the anterior third of the shell is bounded ventrally by a faint spiral groove.

The few traceable parts of the suture line do not differ appreciably from the suture line of *H. grossicostatum* Imlay.

Greatest diameter of holotype 20.5 mm.; height of whorl 10.1 mm.; thickness of whorl 7.7 mm.; width of umbilicus 4 mm.

REMARKS: This species is clearly distinguished from all other species of *Hildoglochiceras* by lacking a ventral keel. Otherwise it is similar to *H. grossicostatum* Imlay with which it is associated.

TYPE: Holotype 17709; paratype 19800, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Durangites* beds). Locality 34 in the Sierra de Parras, Coahuila.

Hildoglochiceras inflatum Imlay, n. sp.

(Plate 4, figures 1-5)

DESCRIPTION: The species is represented by nine specimens. The holotype has been slightly crushed laterally. Shell discoidal, small; whorls ovate in section, a little higher than wide, thickest at middle of flanks, embracing more than three-fourths of preceding whorls; flanks gently convex, below spiral groove inclined toward umbilicus; venter moderately broad, sharpened. Umbilicus fairly narrow and deep, wall vertical at base, rounding evenly into flanks. All specimens are sutured to the end.

The shell is ornamented with faint striae which are strongest at the spiral groove. They are visible at the edge of the umbilicus and disappear on the venter. They describe a curve which is convex backward below the spiral groove, convex forward at the groove, then convex backward on the upper part of the flanks. The venter is merely sharpened on the types and a faint sharpening is visible at a diameter of about 16 mm. The spiral groove is situated at the middle of the flanks and is broad and deep. The depth of the groove varies somewhat on different specimens and even on the two sides of the same specimen.

Dimensions in mm. are as follows:

Specimen	Maximum diameter	Whorl height	Whorl thickness	Umbilical width
holotype 20094	34	16.5	13	7
paratype 15908	32	16	10?	5.
paratype 20002	27	12.5	9.5	4.3
paratype 19379	33.2	15.7	11.	6.5

REMARKS: This species differs from *H. alamense* Imlay by having a broader whorl section, a merely sharpened venter, a more pronounced spiral groove, stronger striae at a comparable size, and an evenly rounded umbilical wall. As the body chamber is unknown, it is impossible to say whether a keel develops on the adult forms.

Among the Indian species of *Hildoglochiceras*, *H.* ? *planum* (Waagen) (1875, p. 56, pl. XI, figs. 3a, b) is distinguished from *H. inflatum* Imlay by a wider umbilicus

and less inflation. *H. subdieneri* Spath (1931, pl. LXXXVI, figs. 3a, b) is more like the Mexican species but has a wider umbilicus.

TYPE: Holotype 20094; paratypes 20002, 19379, 15908, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Substeueroceras* beds). Collections K1, 25, and 26 in Cañón Alamo, Sierra de Jimulco, Coahuila.

Hildoglochiceras alamense Imlay, n. sp.

(Plate 4, figures 6-9, 11, 12)

DESCRIPTION: The species is represented by 11 specimens of which three are smaller than the exposed inner whorl of the holotype. In addition four tiny, immature forms may belong to the species.

Form discoidal, fairly large. Whorls elliptical in section, much higher than wide, enlarging slowly, embracing most of preceding whorls; flanks flattened and wide; venter narrow; rounded on inner whorls, keeled on outer whorls. Umbilicus narrow, shallow; wall low, vertical, rounding abruptly into flanks.

The spiral groove is situated at the middle of the flanks. On the holotype it is broad and shallow but owing to poor preservation is somewhat indistinct. On smaller specimens it is faintly present at a diameter of about 25 mm. The flank ribbing is fine at all stages. The smaller specimens bear nearly microscopic striae which follow the course characteristic of the genus and are strongest on the edges of the venter. The exposed inner whorl of the holotype is so corroded that the striae are preserved only in a few places on the upper part of the flanks. On the outer whorl of the holotype, probably the body chamber, the striae are much stronger, are somewhat variably spaced, and are strongest on the upper parts of the flanks next to the venter. They describe a curve convex forward at the spiral groove and a curve convex backward on the upper part of the flanks, but end abruptly on the venter before reaching the keel. The venter is faintly sharpened at a diameter of about 14 mm. and gradually develops into a low rounded keel anteriorly. The diameter at which a keel appears varies somewhat in different specimens, but on paratype 16936 it is already present at a diameter of 22 mm. Concomitant with the development of the keel the shell on both sides of the median line becomes flattened but does not develop lateral grooves.

The inner whorl of the holotype at a diameter of 53 mm. has a whorl height of 27 mm., a whorl thickness of 14 mm.(?), and an umbilical width of 9 mm.

REMARKS: This species is characterized by its fine ribbing, narrow umbilicus, and flattened flanks. Of the Indian species, it most closely resembles *H. subdieneri* Spath (1931, pl. LXXXVI, figs. 3a, b) which, however, has a wider umbilicus and a merely sharpened venter.

TYPE: Holotype 20001; paratypes 16936, 16937, 20095, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Substeueroceras* beds). Collections K1, 5, and 26 in Cañón Alamo, Sierra de Jimulco, Coahuila.

Genus *Nebrodites* Burckhardt 1910

Nebrodites burckhardti Imlay, n. sp.

(Plate 2, figure 12)

DESCRIPTION: Form fairly large, discoidal, flattened; whorl section subrectangular, much higher than wide; greatest thickness on lower third of flanks; whorls em-

bracing about one-fifth; flanks flattened; venter narrow, flattened on outer whorl. Umbilicus fairly wide, shallow; wall low, vertical on inner whorls, becoming steeply inclined on outer whorl.

The inner whorls, shown in the umbilicus, bear strong, wide ribs which start from the line of involution and cross the flanks nearly radially but incline slightly forward. Most of the ribs bifurcate at or a little below the middle of the flanks. On the penultimate whorl intercalary ribs appear on the upper part of the flanks, and the branching points of the ribs tend to become indistinct. About seven or eight faint constrictions per whorl.

On the outer whorl, which is part of the body chamber, the ribs are strong and broad on the flanks but weakened appreciably along the venter. Their cross-section tends to be triangular rather than rounded. They originate at the line of involution and pass radially onto the flanks where they curve forward slightly, especially near the venter. Most ribs bifurcate below the middle of the flanks, but commonly the bifurcation point is indistinct. Simple ribs and intercalary ribs likewise are present. The ribbing becomes markedly coarser anteriorly on the outer whorl.

Greatest diameter of holotype 120 mm.; height of whorl 31 mm.; thickness of whorl (estimated) 18 mm.; width of umbilicus 58 mm.

REMARKS: *Nebrodites burckhardti* Imlay compared with *N. rota* Burckhardt (1912, p. 96, pl. 22, figs. 1, 9-11) is less involute, has a higher whorl section, and finer ribbing. The frequency of rib bifurcation is similar to *N. crassicostatus* Burckhardt (1912, p. 93, Pl. 21, figs. 1-3, 6) which, however, is more involute, has a rounder whorl section, and rounder, less prominent ribs on the outer whorl.

TYPE: Holotype 19156, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Idoceras* beds). Burckhardt's locality 5, about 2¾ miles (4½ km.) north of San Pedro del Gallo, Durango.

Genus *Simoceras* Zittel 1870

Simoceras sp.

(Plate 6, figure 2)

DESCRIPTION: One internal mold probably represents the inner whorls of this genus. Form flattened, discoidal, evolute; flanks gently convex, rounding into umbilical wall and venter; umbilicus wide and shallow.

The ribs are straight and strong. They start from the line of involution, swell up considerably on the umbilical edge, and give rise to spirally elongated spines at the edge of the venter. On the small part of the venter that is preserved the ribs are wide and weak.

SPECIMEN: 18407, Museum of Paleontology, University of Michigan.

OCCURRENCE: In gray to reddish gray, thin-bedded limestone, transitional from Jurassic to Cretaceous (mapped by Burckhardt as Lower Cretaceous), near center of Cerro del Panteón about 1000 feet west of village and 150 feet northwest of graveyard, San Pedro del Gallo, Durango.

Genus *Waagenia* Neumayr 1878

Waagenia parrasensis Imlay, n. sp.

(Plate 3, figures 8, 12)

DESCRIPTION: The species is represented by one specimen which is mostly covered with iridescent shell. The anterior third of the outer whorl represents the incom-

plete body chamber. The shell is somewhat compressed and broken but must have been fairly flat. Whorls barely embracing to outer row of tubercles; section apparently much higher than wide and becoming relatively higher during growth; flanks rounded on inner whorls, flattened on outer whorls; venter narrow, with moderately deep groove bordered by two tuberculate ridges. Umbilicus fairly wide and shallow; wall rounded and low on inner whorls, becoming moderately high and vertical on outer whorl, rounding rather abruptly into flanks on outer whorl.

The ornamentation of the four inner whorls consists of straight, radially trending ribs which begin at the line of involution and become stronger ventrally. The two outer whorls are marked by three rows of tubercles on each side, by broad, flexuous, indistinct, irregular ribs, and by striae. The ventral tubercles, visible only on the outer whorl, are conical and are separated by slightly narrower interspaces. At the anterior end of the outer whorl there are about seven tubercles per inch. The lateral tubercles, situated high on the flanks, begin at a diameter of about 18 mm. and become very strong anteriorly. They are conical or slightly elongated at right angles to the ribbing. On the penultimate whorl, spines about 8 mm. in length are preserved along the umbilical wall. The umbilical tubercles appear about half a whorl later than the lateral tubercles at a diameter of about 26 mm. and do not become so strong anteriorly. They are slightly elongated parallel to the ribbing. On the two outer whorls the umbilical and lateral tubercles are connected by broad, low, slightly flexuous ribs which are generally strongest near the tubercles and weakest in the middle of the flanks. Some ribs begin at umbilical tubercles and fade out on the upper part of the flanks between lateral tubercles; others begin faintly low on the flanks and may or may not pass ventrally into lateral tubercles. In addition, the anterior half of the outer whorl is marked by numerous faint striae which mostly overlie or are the continuations of ribs.

Greatest diameter of holotype 135 mm.; height of whorl 51 mm.; width of umbilicus 53 mm.; estimated thickness of whorl 24 mm.

REMARKS: *Waagenia parrasensis* Imlay is similar to *W. hybonata* (Oppel) (1863, p. 254, pl. LXXI, figs. 1-3) in regard to coarse tuberculation and high, vertical umbilical wall. In contrast the Mexican form appears to be more compressed and to have closer-spaced ventral tubercles. *Waagenia beckeri* (Neumayr) (1873, p. 202, pl. XXXVIII, figs. 3, 4) has a less vertical umbilical wall, coarser costation, finer tuberculation, a deeper ventral groove, and a thicker whorl section.

TYPE: Holotype 17623, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation. Locality 43 in the Sierra de Parras, Coahuila.

Genus *Aspidoceras* Zittel 1868

Aspidoceras casitense Imlay, n. sp.

(Plate 5, figure 7; Plate 6, figure 11)

DESCRIPTION: Form large, inflated; whorls depressed in section, much wider than high, enlarge slowly, embrace about one-third; flanks narrow and gently convex; venter broadly rounded. Umbilicus wide and deep; wall high and vertical, rounding evenly into flanks. Specimen sutured to anterior end.

The flanks bear two rows of tubercles. The inner row occurs at the edge of the umbilicus and consists of fairly large, round tubercles. The outer row, situated on the upper part of the flanks, consists of much larger tubercles. The outer row of tubercles as preserved in the umbilical opening are produced in spines about a quarter of an inch long, which indicate that the outer whorl bore spines at least

one inch long. The tubercles are irregularly spaced and become wider spaced anteriorly. The tubercles of the two rows are generally opposed and connected by broad low folds which continue faintly across the venter. In addition, the shell is marked with fine radial striations. The thickness of the shell as preserved in the umbilicus and along the line of involution is about 3.5 mm.

Diameter of holotype about 40 mm. from anterior end 105 mm.; height of whorl 38 mm.; thickness of whorl 57 mm.; width of umbilicus 31 mm. Dimensions of whorl one-half volution earlier, given in the same order, are 60, 25, 38, and 20 mm. respectively.

REMARKS: *Aspidoceras casitense* Imlay is characterized by its evolute form and depressed whorl section. *A.* aff. *bispinosum* Burckhardt (not Quenstedt) (Burckhardt, 1912, p. 69, pl. XVI, figs. 1-6) has a higher whorl section and is more involute. *A. subwynnei* Spath (1931, p. 640, pl. CXXII, figs. 5a, b) is like *A. casitense* Imlay in cross-section and arrangement of tubercles but is more involute and has coarser tuberculation. *A.* aff. *hoplisum* (Oppel) in Spath (1931, p. 634, pl. CXVIII, figs. 1a, b) is more involute than the Mexican form, and *A. iphicerum* (Oppel) (1863, p. 218, pl. 60, fig. 2a, b) has a higher whorl section. *A. haupti* Krantz (1928, p. 12, pl. IV, figs. 2 a-b) is slightly more involute, has wider-spaced tubercles, and a smoother venter.

TYPE: Holotype 16983, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Torquatisphinctes* beds). Locality 57 in the Sierra de Parras, Coahuila.

Genus *Pseudopeltoceras* Spath 1928

Pseudopeltoceras? sp.

(Plate 6, figure 1)

DESCRIPTION: One crushed specimen represents parts of two outer whorls of a large form. The smaller whorl (not figured) bears numerous primary and secondary ribs and small tubercles only on the umbilical edge. On the outer whorl the primary ribs are strong, bituberculate and broadly connected across the venter, the secondary ribs have disappeared, and the ventral tubercles are much stronger than the umbilical.

SPECIMEN: 19401, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Gloria formation. Kellum's collection A-16, in Cañón Maravillas, about 2¼ miles southwest of Las Cuevas Ranch, Durango.

Genus *Subgrossouvria* Spath 1924

Subgrossouvria? sp.

(Plate 5, figure 8)

DESCRIPTION: The genus is questionably represented by two specimens. One is a fragment of an outer whorl; the other is a large ammonite with a diameter of about 350 mm. whose inner whorls are not preserved. At a diameter of 220 mm. the whorl bears strong distantly spaced primary ribs on the lower two-thirds of the flanks and numerous faint secondary ribs on the venter. Half a whorl anteriorly at a diameter of about 280 mm. the ridge-like primary ribs extend to the venter which is apparently smooth. At the anterior end of the shell the primary ribs form high, sharp ridges which are about 35 mm. from crest to crest and about 20 mm. in depth.

SPECIMENS: 19308, 15948, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Gloria formation. Kellum's collection A-16 in Cañón Maravillas, about 2¼ miles southwest of Las Cuevas Ranch, Durango.

Genus *Indosphinctes* Spath 1930

Indosphinctes? sp.

(Plate 7, figures 1, 7; Plate 8, figures 1, 2; Text figure 7)

DESCRIPTION: Eight fragments are referred provisionally to *Indosphinctes* on the basis of the fine, perisphinctoid sculpture of the inner whorls and the degree of involution. The development of fairly coarse primary ribs on the outer whorls might suggest a position nearer *Orionoides*.

Specimen 15960 (Pl. 7, fig. 7) shows an immature form fairly well. Its dimensions are as follows: greatest diameter 106 mm., whorl height 45 mm., whorl thickness 32 (?) mm., umbilical width 33 mm. Outer whorl elliptical in section, higher than wide, and embracing slightly more than one-half. Umbilicus fairly narrow and deep; wall oblique and rather high. The ribs are fine and closely spaced. They begin at the line of involution, trend radially on the umbilical wall, curve forward at the edge of the umbilicus, and incline forward slightly on the flanks. Most ribs branch above the middle of the flanks in bundles of twos or threes. On the outer whorl the primary ribs become stronger on the lower part of the flanks, and the branching points of the secondary ribs become indistinct. The inner whorls bear deep constrictions; the outer whorl has five weak constrictions.

Some specimens of larger septate whorls (Pl. 8, figs. 1, 2) may represent different species. The whorl section is slightly higher than wide and embraces about two-fifths. The primary ribs are strong, especially on the edge of the umbilicus, but not distinctly tuberculate. The upper third of the flanks and venter bear numerous secondary ribs of which some are indistinctly connected with the primary ribs.

SPECIMENS: 15960, 19306, 19400, 19307, 15950, 19309, 15961, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Gloria formation. Kellum's collection A-16 in Cañón Maravillas, about 2¼ miles southwest of Las Cuevas Ranch, Durango.

Genus *Torquatisphinctes* Spath 1923

Torquatisphinctes? aff. *bangei* (Burckhardt)

(Plate 9, figure 2)

1919. *Perisphinctes* (*Aulacosphinctes*) *Bangei* BURCKHARDT, Inst. Geol. Mex., Bol., núm. 33, p. 30; 1921, pl. IX, figs. 5-9.

REMARKS: One slightly compressed specimen from the Sierra de Parras probably belongs to this species. The ribs of the inner whorls are a little closer spaced, and the outer whorl bears a few short intercalary ribs which are not present on the type of *T. bangei* (Burckhardt). The ribbing of the inner whorls compares with that of *T. alterneplicatus* (Waagen) (1875, p. 199, pl. L, fig. 2), but the Indian form is distinguished by a different rib curve and a greater number of simple ribs.

SPECIMEN: 16981, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Torquatisphinctes* beds). Locality 57 in the Sierra de Parras, Coahuila.

Torquatisphinctes? sp. ind.

(Plate 9, figure 1)

DESCRIPTION: The outer whorl of the specimen figured has been crushed laterally, but the inner whorls appear to be undeformed. The ribbing of the inner whorls is even finer and closer spaced than on the specimen just described, but the ribbing of the outer whorls is much coarser. Besides, the coiling is more rapid, the point of rib bifurcation is lower, and there are many single ribs at all stages. Most of the ribs bifurcate at or slightly below the middle of the flanks, but some bifurcate on the lower third of the flanks. The ribs begin low on the umbilical wall, incline backward to the edge of the umbilicus, then incline forward on the flanks in a slightly flexuous manner. The coarse ribbing on the outer whorl contrasts markedly with the fine ribbing on the inner whorl and distinguishes the species from all other described Mexican species. There are four or five constrictions per whorl.

REMARKS: This species might be placed in *Lithococeras* except for the projected ribbing of its outer whorl and its rather evolute form. .

SPECIMEN: 19572, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Torquatisphinctes* and *Mazapilites* beds). Locality 46 in the Sierra de Parras, Coahuila.

Genus *Subdichotomoceras* Spath 1925

Subdichotomoceras? sp.

(Plate 10, figure 13; Text figure 7)

DESCRIPTION: Whorls embracing about one-third, depressed in section, much wider than high; flanks rounded, venter broadly rounded. Umbilicus wide, funnel shaped; wall steeply inclined, rounding evenly into flanks.

Shell ornamented with strong, high, fairly widely spaced ribs, which start near the line of involution and trend nearly radially across the flanks and venter. Bifurcation occurs on the upper part of the flanks, and the ribs are highest at the points of bifurcation. The latter are barely visible in the internal whorls. There are a few single ribs. Height of outer whorl 25 mm.; thickness 35 mm.

SPECIMEN: 16979, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Torquatisphinctes* beds). Locality 57 in the Sierra de Parras, Coahuila.

Genus *Aulacosphinctoides* Spath 1923

Aulacosphinctoides? (*Subdichotomoceras*?) sp.

(Plate 10, figures 1-6)

DESCRIPTION: Several small specimens from the Sierra de Parras are obviously the internal whorls, or immature forms, of large perisphinctids. The largest specimen (Pl. 10, figs. 1-3) may be described as follows:

Whorls enlarging slowly, embracing a little less than one-half; inner whorls much wider than high, anterior end of outer whorl slightly wider than high; flanks rounded, venter broadly rounded. Umbilicus fairly wide; wall low and steeply inclined.

Shell ornamented with high, narrow, rather widely spaced ribs which begin low on the umbilical wall and trend nearly radially on the lower part of the flanks. Most ribs bifurcate near or slightly below the middle of the flanks, and the secondary ribs are slightly recurved backward. Two simple ribs and one trifurcating rib are

present on the outer whorl. The ribs are highest at the points of bifurcation. The inner whorls are marked by deep, narrow constrictions. On the outer whorl the ribs along the mid-ventral line are faintly thinned. Greatest diameter 60 mm.; height of whorl 20.5 mm.; thickness of whorl 23.5 mm.; umbilical width 26.5 mm.

The smaller figured specimen (Pl. 10, figs. 4-6) possibly represents the inner whorls of a form as just described. Its flanks are narrowly rounded, and its venter is nearly flat. The whorl section is much wider than high.

REMARKS: Forms such as described here might represent the internal whorls of any of several of the perisphinctoid forms described by Burckhardt (1919, 1921), especially such a form as *"Perisphinctes" alexeii* Burckhardt (1919, p. 20; 1921, pl. IX, figs. 1-4) or *"Perisphinctes (Aulacosphinctes)" diversecostatus* Burckhardt (1919, p. 34; 1921, pl. XII, figs. 1, 2, 4, 5).

SPECIMENS: 16977, 16978, 16980, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Torquatisphinctes* beds). Locality 57 in the Sierra de Parras, Coahuila.

Aulacosphinctoides? aff. *diversecostatus* (Burckhardt)

(Plate 10, figure 7)

1919. *Perisphinctes (Aulacosphinctes) diversecostatus* BURCKHARDT, Inst. Geol. Mex., Bol., núm. 33, p. 34; 1921, pl. 12, figs. 1, 2, 4, 5.

REMARKS: The figured specimen has been considerably mashed but illustrates how much the appearance varies with the preservation. Thus the internal whorls and a part of the outer whorl bear sharp high ribs which contrast greatly with the low, worn ribs at the anterior end of the specimen. Much of the bluntness of the ribs on the perisphinctoid forms from Sierrita del Chivo near Symón, Durango, is due to their preservation as internal molds, whereas the original shell in many species probably bore high, sharp ribs.

SPECIMEN: 17622, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation. Locality 43 in the Sierra de Parras, Coahuila.

Genus *Subplanites* Spath 1925

Subplanites? sp.

(Plate 9, figures 13-15; Text figure 7)

DESCRIPTION: Several specimens probably belong to this genus. A small specimen (Pl. 9, figs. 14, 15) shows several internal whorls and may be described as follows: Whorls subquadrate in section, wider than high, embracing about one-half; flanks slightly convex, fairly broad, rounding rapidly into venter; venter broadly rounded. Umbilicus fairly wide and deep; wall vertical and fairly high, rounding rapidly into flanks.

The ribs are fairly low, narrowly rounded, and well separated. They begin near the middle of the umbilical wall, curve backward to the edge of the umbilicus, incline forward on the flanks, and arch forward slightly on the venter. Simple ribs are about a third as common as forked ribs. Bifurcation generally takes place on the upper third of the flanks, but some of the ribs bifurcate near the middle of the flanks, and one of the branches in turn bifurcates on the upper third. Constrictions are generally bounded by ribs which bifurcate at the edge of the umbilicus, and one of the branches commonly bifurcates again higher up. The points of bifurcation are

generally slightly swollen. There are five pronounced constrictions on the outer whorl. The mid-ventral line is marked by a distinct thinning of the ribs.

At a diameter of 51 mm. the whorl height is 18.5 mm., the whorl thickness is 22 mm., and the umbilical width is 20 mm.

A large specimen (Pl. 9, fig. 13; Text figure 7) from the same locality might represent the adult form of the specimen described above. Its whorl section is about as high as wide; its umbilical wall is vertical. The ribs are high, narrowly rounded, and bi- or trifurcate at or slightly above the middle of the flanks. They curve backward on the umbilical wall but incline forward on the flanks. There is one pronounced constriction. Only a small part of the venter is preserved, but there is no indication of a mid-ventral thinning.

SPECIMENS: 19546, 19557, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Idoceras* beds). Burckhardt's locality 4, San Pedro del Gallo, Durango.

Genus *Idoceras* Burckhardt 1906

Idoceras viverosi Burckhardt

(Plate 13, figures 1-3)

1906. *Idoceras viverosi* BURCKHARDT, Inst. Geol. Mex., Bol., núm. 23, p. 61, Pl. 15, figs. 4-7.

REMARKS: In the University of Michigan collections from San Lazaro Canyon, Nuevo León, are four specimens of this species. The largest is a little smaller than the holotype and is crushed laterally. The specimen figured shows the internal whorls better than the holotype. On the three inner whorls the ribs are high and narrow, and the whorl section is wider than high. On the outer whorl the ribs become wide, and the whorl section much higher than wide.

Dimensions in mm. are as follows:

Specimen	Greatest diameter	Whorl height	Whorl thickness	Umbilical width
holotype (unknown)	76	30	22	30
hypotype 19517	47	19	14	16.5

OCCURRENCE: (*Idoceras* beds). (1) Holotype from Cañón de San Matias, near Casa Sotelo, Sierra de Santa Rosa, Zacatecas; (2) hypotype from San Lazaro Canyon, Nuevo León.

Idoceras involutum Imlay n. sp.

(Plate 12, figures 3, 4)

DESCRIPTION: Form discoidal, moderate in size for genus; whorl section subquadrate, higher than wide, thickest on lower fourth of flanks; whorls embracing three-fourths; flanks slightly convex, sloping gently toward venter; venter moderately broad and evenly rounded. Umbilicus fairly narrow and deep; wall fairly high for genus, steeply inclined, rounding evenly into flanks.

The inner whorls, shown in the umbilical opening, bear strong, closely set ribs which are separated by slightly wider interspaces on the three inner whorls but on the fourth whorl are about the same width as the interspaces. The ribs begin low on the umbilical wall and incline forward slightly on the flanks.

On the outer whorl are about 28 primary ribs which begin low on the umbilical wall, pass radially onto the flanks where they incline forward and become flexuous, and then incline forward rather strongly on the venter. These primary ribs are

broad and low and some become rather indistinct near the middle of the flanks. Most of them bifurcate or trifurcate on the upper third of the flanks. A few ribs bifurcate near the middle of the flanks, and one or both branches bifurcate on the upper third. In addition, many short intercalary ribs occur on the upper part of the flanks. The secondary ribs are much more pronounced but narrower than the primary ribs. Inconspicuous radial striae occur at intervals. Faint constrictions are on all the whorls. The ribs are much weakened along the midventral line, and in general there is an alternation of ribs on the opposite sides of the venter. The venter of the outer whorl bears about 95 ribs.

Greatest diameter of holotype 96 mm.; width of umbilicus 27.5 mm.; height of last whorl 39 mm.; thickness of last whorl 26 mm.

REMARKS: *I. involutum* Imlay may be recognized by its degree of involution and its few, broad primary ribs. *I. subdedalum* Burckhardt (1906b, p. 63, pl. 13, figs. 5-8) has a narrower venter and more numerous, sharper primary ribs. *I.* aff. *dedalum* (Gemmellaro) sp. Burckhardt (1912, p. 125, pl. 33, figs. 1-6) has a narrower venter, a higher whorl section, and nearby effaced ribs on the flanks of the body whorls.

TYPE: Holotype 19496, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Idoceras* beds). San Lazaro Canyon, Nuevo León.

Idoceras striatum Imlay, n. sp.

(Plate 13, figures 4-8; Text figure 7)

DESCRIPTION: Form flattened, discoid; whorl section compressed-ovate, higher than wide at all stages but becoming more depressed during growth; whorls embracing slightly more than one-half; flanks flattened; venter gently convex, tending to become flattened at anterior end of holotype. Umbilicus fairly narrow, moderate in depth; wall steeply inclined, on outer whorl rounding rather abruptly into flanks. On holotype the incomplete body chamber is represented by most of the outer whorl.

The ribs of the inner whorls, as shown in the umbilical opening, are close set and moderately strong. They begin at the line of involution and curve forward slightly on the flanks, a few bifurcating low on the flanks. On the outer whorl the ribs begin at the line of involution, curve backward on the umbilical wall, recurve abruptly at the base of the flanks and incline forward strongly, become slightly flexuous and less inclined on upper part of flanks, and then incline forward a little stronger on the venter. On the posterior half of the outer whorl the ribs bifurcate near or somewhat below the middle of the flanks, and one on both branches bifurcates again on the upper third of the flanks. Other ribs bifurcate only on the upper third of the flanks, and a few remain simple throughout their course. The flank ribbing is moderately strong at the posterior end of the outer whorl but becomes weaker anteriorly and on the anterior half is replaced by striae which tend to be grouped in bundles. On the venter the ribs remain strong and are replaced by striae only immediately anterior to constrictions. On the posterior three-fourths of the outer whorl the venter is marked by a narrow smooth band, but on the anterior fourth the ribs cross the venter with only slight diminution in strength. The outer whorl of the holotype bears eight constrictions which are weak on the right side and fairly pronounced on the left side.

The suture line is characteristic of the group of *Idoceras durangense*. The siphonal lobe is a little shorter than the first lateral lobe. The latter has a wide trunk and is subsymmetrically divided by three main branches. The second lateral lobe is short and wide. There are three oblique auxiliary lobes. External saddle wide and bifid. First lateral saddle higher and narrower than external, asymmetrically subdivided.

Greatest diameter of holotype 77 mm.; height of whorl 30 mm.; thickness of whorl 20.5 mm.; width of umbilicus 23.5 mm.

TYPE: Holotype 19492, Museum of Paleontology, University of Michigan.

REMARKS: *Idoceras striatum* Imlay may be recognized by its striate body chamber and the common bifurcation of ribs low on the flanks. *Idoceras johnsoni* Burckhardt (1912, p. 114, pl. 25, figs. 6, 10-12) is slightly less involute, has coarser ribbing, and bifurcation occurs only on the upper part of the flanks. A fragment of a large specimen collected near La Escondida, Nuevo León, has a steeper umbilical wall than the holotype but may be distorted.

OCCURRENCE: La Casita formation (*Idoceras* beds). (1) Holotype from San Lazaro Canyon, Nuevo León; (2) Questionably 7 miles (11.2 km.) from La Escondida about 100 yards south of road to Soledad, Nuevo León.

Idoceras sanlazarense Imlay, n. sp.

(Plate 11, figures 3-6)

DESCRIPTION: Form flattened, discoid; whorl section compressed ovate in early stages, a little convergent in later stages, and becoming higher during growth; whorls embracing about one-half; flanks nearly flattened, rounding evenly into venter; venter gently convex, becoming narrower during growth. Umbilicus fairly deep, moderate in width, tending to become slightly wider during growth; wall fairly high, nearly vertical on inner whorl steeply inclined on outer whorls, rounding rather abruptly into flanks. The incomplete body chamber is represented by the anterior half of the outer whorl of the holotype 19519 and by the outer whorl of paratype 19497 (Pl. 11, figs. 4-6).

On the inner whorls up to a diameter of about 25 mm. the ribs are wide, strong, rounded, and separated by wider interspaces. They begin at the line of involution, trend nearly radially across the flanks, and arch forward on the venter which they cross with only slight diminution in strength. Bifurcation is common on the upper part of the flanks.

On the outer whorls the ribs are wide, strong, rounded, and as wide or wider than the interspaces. They begin at the line of involution, incline forward slightly on the flanks, and become a little flexuous on the body whorl. They arch forward on the venter to form chevrons but undergo only slight diminution in strength except on the body chamber where a narrow, smooth band is developed. Almost all ribs bifurcate, or trifurcate, on the upper third of the flanks. Some bifurcate as low as the middle of the flanks and in turn one or both branches bifurcate again on the upper third. Bifurcation rarely takes place as low as the base of the flanks. The upper part of the flanks bear some intercalary ribs. At all stages the secondary ribs are narrower but more pronounced than the primary ribs. This relationship is most pronounced on the body chamber where the primary ribs become broad and faint and the secondary ribs somewhat stronger. Fine, radial striae occur at irregular intervals on the outer whorls and are most common on the body whorl. About six or seven weak constrictions per whorl. Paratype 19498 at a diameter of 63 mm. has 42 primary ribs.

Dimensions in mm. are as follows:

Specimen	Greatest diameter	Umbilical width	Whorl height	Whorl thickness
holotype 19519	78	27	29	17.5
paratype 19498	63	20	24.5	17.5
paratype 19520	51.5	18	19.5	14.5

REMARKS: *Idoceras sanlazarense* Imlay closely resembles *I. santarosanum* Burckhardt (1906b, p. 58, Pl. 14, figs. 6, 7) but is more involute and has a higher, steeper umbilical wall.

TYPE: Holotype 19519; paratype nos. 19497, 19498, 19520, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Idoceras* beds). San Lazaro Canyon, Nuevo León.

Idoceras tamaulipanum Imlay, n. sp.

(Plate 12, figures 1, 2)

DESCRIPTION: Form discoidal, fairly large; whorl section ovate, higher than wide, thickest at edge of umbilicus; whorls embracing a little more than one-half; flanks flattened below, slightly convergent above and rounding evenly into a moderately wide venter. Umbilicus moderate in width and depth; wall fairly low, vertical on inner whorls, almost vertical on outer whorl, rounding abruptly into flanks.

The inner whorls, shown in the umbilical opening, bear straight, high, narrowly rounded ribs, which begin at the line of involution, pass radially onto the flanks and then incline forward. The interspaces are slightly wider than the ribs.

On the outer whorl the ribs are straight, pronounced, fairly wide and separated by interspaces of similar width. They begin at the line of involution, incline forward on the flanks, and bend forward conspicuously on the venter. Their strength increases from the umbilicus to the venter where some ribs are nearly effaced and others connect with the ribs of the opposite flanks. Bifurcation occurs on the upper third of the flanks. The bifurcating ribs are commonly separated by one or two simple ribs. There are a few short intercalary ribs. Radial striae are present at irregular intervals. Constrictions are narrow and inconspicuous.

At a diameter of 86 mm. the holotype has an umbilical width of 28 mm., a whorl height of 33 mm., and whorl thickness of 21 mm.

REMARKS: *Idoceras tamaulipanum* Imlay is distinguished by its straight, strong, frequently unforked ribs and by its vertical umbilical wall. None of the described Mexican species resembles it closely.

TYPE: Holotype 19494, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Idoceras* beds). San Lazaro Canyon, Nuevo León.

Idoceras densicostatum Imlay, n. sp.

(Plate 8, figures 3-5)

DESCRIPTION: Form discoidal, small; whorl section ovate, higher than wide, thickest at edge of umbilicus; whorls embracing about three-fifths; flanks slightly convex, sloping gently toward venter; venter moderate in width, evenly rounded. Umbilicus fairly narrow and deep; wall moderate in height, steeply inclined, rounding rather abruptly into flanks.

On the outer whorl of the holotype the ribs are fine, sharp, and close set but separated by much wider interspaces. They begin at the umbilical wall, pass nearly radially onto the flanks, then incline forward to the venter where they bound a broad, nearly smooth, midventral area. Bifurcation occurs commonly on the upper third of the flanks, but some ribs bifurcate as low as the middle of the flanks, and a few bifurcate at the edge of the umbilicus. Many of the bifurcation points are indistinct. In addition there are a few simple ribs, which extend from the umbilicus to the venter without bifurcating, and many short intercalary ribs on the edge of the venter.

Toward the anterior end of the shell the ribs become more pronounced on the venter and on the lower part of the flanks than on the middle of the flanks, and the secondary ribs become broader than the primary ribs. Radial striae occur at irregular intervals. Constrictions are faint except for one near the anterior end of the holotype. The venter of the outer whorl bears about 110 ribs.

The ornamentation of the inner whorls, shown on two small specimens, is essentially like that of the holotype except that the ribs are of about the same strength throughout their course and are only slightly reduced on the venter.

Greater diameter of holotype 50 mm.; width of umbilicus 14.5 mm.; height of last whorl 21 mm.; thickness of last whorl 14 mm.

REMARKS: *Idoceras densicostatum* Imlay may be distinguished easily from other Mexican forms by its fine, dense costation. *I. zacatecanum* Burckhardt (1906b, p. 42, Pl. 9, figs. 1-4) approaches most closely but has coarser ribbing and is more evolute.

TYPE: Holotype 19518; paratype 19488, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Idoceras* beds) 7 miles (11.2 km.) from La Escondida about 100 yards south of road to Soledad, Nuevo León.

Genus *Virgatisphinctes* Uhlig 1910

Virgatisphinctes sp. juv.

(Plate 6, figures 3-5)

DESCRIPTION: One small immature form is worth recording because of its occurrence with *Substeueroceras* in the highest Jurassic beds.

Outer whorl subovate in section at posterior end, becoming subquadrate at anterior end, a little higher than wide, embracing about one-fourth; flanks flattened and nearly parallel, rounding evenly into venter and abruptly into umbilical wall; venter fairly broad and somewhat flattened. Umbilicus fairly narrow and deep, wall steeply inclined.

The shell is ornamented with ribs and striae. The primary ribs begin at the line of involution, curve backward strongly on the umbilical wall, recurve at the edge of the umbilical wall and incline forward on the flanks, being slightly inflected forward in the lower part, and then cross the venter transversely. On the lower part of the flanks the primary ribs are strong, narrowly rounded, widely spaced, and covered and separated by nearly microscopic striae. Near the middle of the flanks the primary ribs pass into bundles of two or three slightly smaller ribs which cross the venter without diminution in strength. These bundles of ribs are separated by one to three intercalary ribs which originate on the upper third of the flanks as continuations of some of the striae. On the venter all ribs are of equal strength.

Greatest diameter of figured specimen about 31.5 mm.; whorl height, 15.5 mm.; whorl thickness, 14.5 mm.; umbilical width, 10 mm.

SPECIMEN: 20096, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Substeueroceras* beds). Collection K1 in Cañón Alamo, Sierra de Jimulco, Coahuila.

Genus *Involuticeras* Salfeld 1913

Involuticeras sp. ind. juv.

(Plate 6, figures 6, 7)

DESCRIPTION: One immature form of this genus is worth recording because it is much coarser ribbed than the species described by Burckhardt (1906b, p. 98-100, Pl.

XVII, figs. 1-4; Pl. XVIII, figs. 1-3) from Mazapil, although possibly close to *I. praecursor* (Burckhardt).

Whorl section subquadrate in section, higher than wide; flanks flattened but converging slightly ventrally; venter arched. Umbilicus narrow, wall slightly overhanging.

The ribs are flexuous, become strongest ventrally, are variously branched or simple, and are not weakened on venter. They begin on the umbilical wall and curve backward to the lower fourth of flanks, then curve forward to the upper part of the flanks, where they recurve slightly and cross the venter transversely. Di- and bi-dichotomy occur at various heights from the lower third to the upper third of the flanks. Many secondary ribs are loosely connected with the primary ribs, and there are a number of intercalary ribs. Anteriorly the ribs become fainter on the lower part of the flanks but remain strong on the venter.

SPECIMEN: 19528, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Caja formation, about 100 feet from base (*Glochiceras fialar* beds). About 2 miles south-southeast of Melchor Ocampo just south of crest of Sierra Zuloaga, Zacatecas.

Genus *Aulacosphinctes* Uhlig 1910

Aulacosphinctes sp.

(Plate 15, figures 10, 11)

DESCRIPTION: Two specimens from the Sierra de Jimulco are the sole representatives of this genus in a large faunal assemblage dominated by *Substeueroceras*. The larger specimen has been compressed laterally.

Form discoidal; whorls barely embracing; inner whorls wider than high; outer whorl probably nearly as wide as high before compression; flanks convex, becoming flatter on outer whorl. Umbilicus wide; wall fairly high and nearly vertical on outer whorl, rounding evenly into flanks.

The inner whorls, which are poorly preserved, bear fine ribs of which the majority are simple and the remainder bifurcate above the middle of the flanks. The ribs terminate ventrally in radially elongate tubercles which bound a narrow, smooth midventral area.

On the outer whorl of the larger specimen the ribs are fairly low, flexuous, incline forward on the flanks, are greatly reduced in strength along the midventral line, and are separated by much wider interspaces. Some of the ribs are slightly swollen at the edge of the umbilicus, and most of them are swollen at the edge of the ventral depression. The ribs begin at the line of involution, curve backward slightly to the edge of the umbilicus, then curve forward to the middle of the flanks where they recurve slightly and cross the venter transversely. Simple ribs outnumber the forked ribs. Bifurcation occurs below or at the middle of the flanks. Some of the interspaces on the outer whorl are a little wider and deeper than the rest and might be considered constrictions.

REMARKS: Because of its poor preservation, this species cannot be positively identified with any of the Mexican species (Burckhardt, 1912, p. 138, 139, Pl. XXXV, figs. 1-3, 7, 9; 1919, p. 50-53; 1921, Pl. XVII, Pl. XVIII, fig. 1), but its general appearance is like *A. torresianus* Burckhardt (1919, p. 52; 1921, Pl. XVII, figs. 4-6).

SPECIMENS: 20004 and 20045, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Substeueroceras* beds): Locality K 5 in Cañón Alamo, Sierra de Jimulco, Coahuila.

Genus *Micracanthoceras* Spath 1925

Micracanthoceras acanthellum Imlay, n. sp.

(Plate 16, figures 8-11)

DESCRIPTION: The species is represented by four specimens. Shell discoidal; whorls ovate in section, wider than high in early stages, becoming as high as wide in later stages, embracing about one-fourth; flanks gently convex; venter fairly broad, somewhat flattened. Umbilicus fairly wide; wall moderate in height, vertical at base, rounding evenly into flanks.

The inner whorls bear fine flexuous ribs of which the majority are simple. Bifurcation occurs below or at the middle of the flanks, and the points of bifurcation are commonly strongly tuberculate. Most of the simple ribs are likewise swollen or weakly tuberculate near the middle of the flanks. Ventrally all ribs terminate in tubercles of varying prominence which border a nearly smooth midventral area.

On the outer whorl of the holotype the ribs are low, rounded, and slightly flexuous. They begin low on the umbilical wall and trend radially, or slightly backward, to the edge of the umbilicus. They are nearly straight or slightly inflected forward near the middle of the flanks, and all have a slight forward curvature at the margin of the venter. Simple ribs are less common than forked ribs and are disposed irregularly. Bifurcation occurs near the middle of the flanks, and the points of bifurcation are swollen. Some of the simple ribs bear slight swelling near the middle of the flanks. Ventrally all ribs terminate in radially elongate swellings of varying prominence which bound a narrow, smooth midventral area or are continued weakly across the venter. Tuberculation becomes relatively weaker with growth. Near the anterior end of the holotype there appears to be a weak constriction.

At a diameter of 46 mm. the holotype has a whorl height of 16.5 mm., a whorl thickness of 16.5 mm., and an umbilical width of 18.5 mm. Maximum diameter of holotype, 50 mm.

REMARKS: This species is distinguished from the associated Mexican species by its flexuous ribs and weaker tuberculation. It is possibly close to the Argentine *Hoplites microcanthus* of Burckhardt (1903, p. 58, Pl. X, figs. 12-16), but its ribs appear to be closer spaced and more flexuous. *M.* aff. *microcanthum* (Oppel) in Spath (1931, p. 543, Pl. XCII, figs. 3a, b) has a more depressed whorl section and straighter ribs.

TYPE: Holotype 19580; paratypes 19604, 19602, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation, collected by Mexican helpers supposedly at Burckhardt's locality 11 but probably near the northeastern part of Cerro de la Cruz, San Pedro del Gallo, Durango.

Micracanthoceras aguajitense Imlay, n. sp.

(Plate 14, figures 5-7)

1912. *Hoplites* sp. ind. BURCKHARDT, Inst. Geol. Mex., Bol., núm. 29, p. 142, Pl. XXXVI, figs. 4-6.

DESCRIPTION: Burckhardt's description may be translated as follows:

"Shell composed of whorls which embrace about one-half and do not increase very rapidly. Flanks convex, passing insensibly into a low but abrupt umbilical wall. Venter wide, somewhat flattened. Transverse section wider than high, depressed. The umbilicus is narrow and of little depth.

"From the suture [line of involution] pass thin but projecting principal ribs, which are directed obliquely forward and are completely straight. The majority of these

ribs subdivide into two, or more rarely into three, branches at the middle of the flanks and generally, but not always, at the point of division, they form a more or less pronounced median tubercle. The ribs pass over the venter without interruption, but they are, however, attenuated at their median part. At irregular intervals along the ventral depression some ribs bear a large ventral tubercle, and sometimes two ribs, issuing from distinct principal ribs, are reunited in a single ventral tubercle."

Three specimens in the University of Michigan collections belong to this species. The largest, selected as the holotype, has parts of two whorls beyond that shown in Burckhardt's original figure. On these outer two whorls the ribs become much stronger and wider spaced anteriorly, and the tubercles become relatively weaker. The most anterior part of the outer whorl of the holotype (Pl. 14, figs. 6, 7) is not figured because of poor preservation.

REMARKS: This species, although imperfectly known, may be distinguished from *M. microcanthum* (Oppel) (Zittel, 1868, p. 93, Pl. XVII, figs. 1-5) by the finer ornamentation of its inner whorls.

TYPE: Holotype 19588; paratypes 19589, 19598, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation. (1) Collected by Mexican helper supposedly at Burckhardt's locality 11 but probably near the northeastern part of Cerro de la Cruz. (2) Burckhardt's locality 24, San Pedro del Gallo, Durango.

Micracanthoceras n. sp. aff. *koellikeri* (Oppel)

(Plate 17, figures 2-4)

DESCRIPTION: The species is represented by two specimens of which one shows parts of two whorls. Whorls wider than high, outer whorl more depressed than the inner; flanks convex; venter broadly convex, slightly flattened along midline; umbilical wall vertical at base, rounding evenly into flanks.

The inner whorl has high, widely spaced, radially inclined ribs which bear pronounced tubercles near the middle of the flanks. The outer whorl has high, narrow, flexuous ribs of which about half bifurcate near the middle of the flanks. The ribs begin at the line of involution, curve backward to the umbilical edge, then curve forward on the lower part of the flanks, and recurve backward on the upper part of the flanks. In the case of forked ribs the anterior branch appears as a continuation of the primary rib, and the posterior branch is deflected slightly backward near its base. The bifurcation points, as well as the ventral terminations of the ribs, bear more or less prominent, radially elongate tubercles. The simple ribs bear less prominent tubercles, or swellings, near the middle of the flanks. At one place a weak secondary rib is given off from a primary at the umbilical edge and does not become tuberculate. The ventral groove is narrow and faintly marked in several places by rib continuations.

Dimensions of figured specimen at anterior end: whorl height 13 mm.; whorl thickness 10.5 mm.

REMARKS: This species is distinguished from the associated Mexican species described here by its widely spaced, prominent ribs and pronounced tubercles. *M. koellikeri* (Oppel) (Zittel, 1868, p. 95, Pl. 18, figs. 1, 2; Krantz, 1928, p. 28, Pl. III, figs. 1a, b) appears to have a more compressed whorl section, weaker ribbing, and weaker tuberculation. The Argentine form figured by Steuer (1897, p. 31; Pl. 8, figs. 5, 6) is more evolute but has similar ribbing. *Corongoceras lotenoense* Spath (1925, p. 144; Haupt, 1907, p. 201, Pl. 9, fig. 7) at first glance appears similar but has a differently ornamented venter, a higher whorl section, and a slightly different rib curve.

SPECIMENS: 19590, 19592, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation, collected by Mexican helper supposedly at Burckhardt's locality 11, but probably from northeast part of Cerro de la Cruz, San Pedro del Gallo, Durango.

Micracanthoceras cf. *microcanthum* (Oppel)

(Plate 7, figures 2, 3)

1912. *Hoplites microcanthus* BURCKHARDT, Inst. Geol. Mex., Bol., núm. 29, p. 141, Pl. XXXVI, figs. 1-3, 9.

REMARKS: One immature specimen shows the inner whorls excellently. Compared with *M. aguajitense* Imlay the ribs are higher, thinner, inclined more strongly forward, wider spaced, and bifurcate more commonly; the tubercles are less prominent; and the whorl section is more depressed.

SPECIMEN: 19597, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation, collected by Mexican helper supposedly at Burckhardt's locality 11 but probably from northeast part of Cerro de la Cruz, San Pedro del Gallo, Durango.

Micracanthoceras alamense Imlay, n. sp.

(Plate 9, figures 3-12)

DESCRIPTION: The species is represented by six specimens which show 3½ inner whorls. Whorls subovate in section, wider than high, embracing about one-third; flanks gently convex, becoming less convex on outer whorl of largest specimens; venter fairly broad, somewhat flattened. Umbilicus moderate in width; wall moderate in height, vertical at base, rounding evenly into flanks.

The ribs are high, narrow, and nearly straight or inflected slightly forward near the middle of the flanks. They begin at the line of involution and trend radially or slightly backward to the edge of the umbilicus and are directed a little forward on the flanks. Simple ribs are about one-third as common as forked ribs and are disposed irregularly. Bifurcation commonly occurs near the middle of the flanks and rarely as low as the umbilical edge. The bifurcation points are swollen or weakly tuberculate. Some of the simple ribs are likewise swollen near the middle of the flanks. Ventrally all ribs pass into radially elongate swellings of varying prominence which are partially interrupted along the midventral line. The internal mold, however, bears a distinct ventral groove.

Dimensions in mm. are as follows:

Specimen	Diameter	Whorl height	Whorl thickness	Umbilical width
paratype 20049	16.0	6.5	7.0	5.5
holotype 20047	...	9.3	9.7	8.8
paratype 15902	27.5	11.0	11.0	9.0

REMARKS: This species is similar to *Micracanthoceras aguajitense* Imlay but is distinguished by a more rapid rate of coiling, weaker tuberculation, a less distinct ventral depression, fewer simple ribs, and a relatively higher whorl section.

TYPE: Holotype 20047; paratypes 20048, 20049, 15902, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Substeueroceras* beds). Kellum's collections 5 and 25 in Cañón Alamo, Sierra de Jimulco, Coahuila.

Micracanthoceras n. sp. ind.

(Plate 17, figures 1, 5)

DESCRIPTION: One small form is characterized by extremely high, thin ribs of which most are simple. About every third or fourth rib bifurcates at or below the middle of the flanks and gives rise to a prominent, thin spine at the point of furcation. Some of the simple ribs are likewise somewhat swollen near the middle of the flanks. Some of the ribs are inflected forward slightly on the flanks but recurve slightly on the venter. Ventrally the ribs are produced in radially elongate spines of considerable prominence which terminate abruptly at an extremely narrow midventral depression across which the ribs extend faintly.

SPECIMEN: 20044, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Substeueroceras* beds). Kellum's collection 5 in Cañón Alamo, Sierra de Jimulco, Coahuila.

Genus *Kossmatia* Uhlig 1910

Kossmatia sp.

(Plate 1, figures 5, 6)

DESCRIPTION: One fragment is worth recording because of its importance as a stratigraphic marker in the Sierrita del Chivo section. It does not appear to belong to any described Mexican species.

The whorl section is higher than wide, the venter is flattened, and the flanks are slightly convex. The ribs are high, strong, and rather widely spaced. They trend nearly radially on the lower part of the flanks, become highest at the middle of the flanks where they bifurcate. The secondary branches curve forward on the flanks and form pronounced chevrons on the venter. There are examples of simple and intercalary ribs.

SPECIMEN: 19422, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Caja formation (*Kossmatia* beds). Bed 10 (collection 7) of Imlay's section on the north side of Cañón del Toboso, Sierrita del Chivo, near Symón, Durango.

Genus *Durangites* Burckhardt 1910

Durangites astillerensis Imlay, n. sp.

(Plate 10, figures 10-12)

DESCRIPTION: Shell small, discoidal; whorls ovate in section, wider than high in early stages, becoming as high as wide in late stages; outer whorl embracing about one-fourth; flanks convex; venter nearly evenly rounded, slightly flattened along midventral line. Umbilicus fairly wide and shallow; wall nearly vertical at base, inclined above and rounding evenly into flanks. Long lateral lappets are preserved at the anterior end of the holotype.

The inner whorls bear high, narrow ribs which start at the line of involution, incline forward slightly on the flanks, and become stronger ventrally. A few ribs bifurcate below the middle of the flanks.

On the penultimate whorl the ribs become much higher anteriorly but remain rather narrow. About every third or fourth rib bifurcates near the middle of the flanks, and the points of bifurcation bear prominent tubercles. The simple ribs are more or less

swollen near the middle of the flanks but are never so strongly tuberculate as the forked ribs.

On the outer whorl the ornamentation changes considerably. The posterior part bears high, narrow, tuberculate ribs as on the penultimate whorl. The ribs are nearly radial on the umbilical wall but incline forward strongly on the flanks and cross the venter transversely. In addition to prominent lateral tubercles, the ribs terminate ventrally in ventral tubercles of varying prominence which bound a narrow ventral furrow. Commonly the posterior rib of a pair of secondaries bears the most prominent ventral tubercle, but there are exceptions. In one place a lateral tubercle gives rise to three secondaries, and in another place two simple ribs terminate in a common ventral tubercle. The ventral furrow is crossed by the ribs which are only partly reduced in strength where the shell is preserved, but on the internal mold the ribs distinctly terminate at the ventral furrow.

The anterior part of the outer whorl is represented by an internal mold, and the ribs do not appear so prominent as on the posterior part. However, it seems likely that the ribbing on the shell would be as vigorous as on the posterior part, although less strongly tuberculate. On the anterior part the ribs trend radially on the umbilical wall, incline forward on the lower part of the flanks, then recurve on the upper part, and cross the venter with a slight arching toward the rear. Simple ribs are as numerous as forked ribs but exhibit no regular arrangement. The bifurcation points become less strongly tuberculate anteriorly and on the anterior half are merely swollen. At the anterior end of the holotype the ribs cross the venter with scarcely any diminution in strength, and the ventral tubercles have disappeared. As this part is preserved as an internal mold, the original shell probably bore only the faintest imprint of a ventral depression.

Greatest diameter of holotype 33 mm.; height of whorl 10.7 mm.; thickness of whorl 10.7 mm.; umbilical width 14.5 mm.

REMARKS: Among the various Mexican species, the present species most approaches *Durangites vulgaris* Burckhardt (1912, p. 149, Pl. XXXVII; Pl. XXXVIII, figs. 1-4) in proportions but may be distinguished by its coarser ornamentation and its greater number of simple ribs. *D. acanthicus* Burckhardt (1912, p. 146, Pl. XXXVI, figs. 7, 8, 10, 11, 15) has a slightly higher whorl section, a narrower umbilicus, flatter flanks, and less flexuous ribs. *D. incertus* Burckhardt (1912, p. 147, pl. XXXVI, figs. 12-14, 16, 17) is much like the present species in general appearance but has a higher whorl section, a narrower umbilicus, and less flexuous ribs.

TYPE: Holotype 17707; paratype 20008, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Durangites* beds). Locality 34 in the Sierra de Parras, Coahuila.

Durangites cf. *acanthicus* Burckhardt

(Plate 17, figures 6, 7)

REMARKS: The specimen figured is much larger than the type of *D. acanthicus* Burckhardt (1912, p. 146, pl. XXXVI, figs. 7, 8, 10, 11, 15), but its form and ornamentation are similar. Especially noteworthy is the persistence of prominent ventral tubercles to a late stage of development.

SPECIMEN: 20009, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Durangites* beds). Locality 34 in the Sierra de Parras, Coahuila.

Durangites rarifurcatus Imlay, n. sp.

(Plate 17, figures 8, 9)

DESCRIPTION: Two specimens from Cañón Alamo almost certainly represent the same species but because of their difference in size only the larger specimen is definitely assigned to the species.

Form discoidal, compressed; whorls ovate in section, a little higher than wide, embracing slightly; flanks gently convex; venter moderate in width. Umbilicus fairly wide and shallow; wall oblique on innermost whorls, becoming vertical on outer whorls, rounding evenly into flanks at all stages.

A small specimen consists of inner whorls (Pl. 17, fig. 9). Up to a diameter of about 30 mm. the ribs are narrow, fairly close spaced, moderate in height, trend radially across the flanks, and nearly all are simple. Bifurcation rarely occurs low on the flanks, or at the edge of the venter. A few ribs bear lateral tubercles or swellings, and most ribs are more or less strongly swollen on the edges of the venter. The ribs are only slightly reduced in strength along the midventral line. At a diameter greater than about 30 mm. the ribs become fairly wide spaced, much stronger, and more frequently bifurcate although simple ribs predominate.

On the holotype the inner whorls are not well exposed but appear to be like those described above. On the two outer whorls the ribs are wide spaced, strong, and mostly simple. Bifurcation occurs at or above the middle of the flanks, and some of the posterior secondary ribs are poorly united with the primary ribs. There are no lateral tubercles on the outer whorls and only suggestions of ventral swellings.

The holotype is so compressed that its proper dimensions cannot be measured. Specimen 20090 at a diameter of 28 mm. has a whorl height of 10 mm. and an umbilical width of 12 mm.

REMARKS: This species may be distinguished by its large number of simple ribs, its wide umbilicus, and the contrast in rib spacing between the inner and the outer whorls.

TYPE: Holotype 20088, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Durangites* beds). Collection K2 in Cañón Alamo, Sierra de Jimulco, Coahuila.

Durangites n. sp. ind.

(Plate 17, figures 10-12)

DESCRIPTION: Two specimens of *Durangites* represent the entire collection from locality 4 in Cañón Alamo. The specimens possibly belong to the same species and are certainly distinct from any described species. The larger specimen is the largest known representative of the genus.

The smaller specimen (Pl. 17, figs. 10, 11) has a subquadrate whorl section which is a little higher than wide. The flanks and venter are nearly flattened. The umbilicus is fairly wide and shallow. The ribs are strong, high, and widely spaced. Most of them are simple, but some bifurcate at or above the middle of the flanks. The bifurcation points are feebly tuberculate. Several short intercalary ribs are present. Every fourth or fifth rib passes into a pronounced ventral tubercle. The other ribs are merely swollen on the venter. All ribs undergo considerable diminution in strength along the midventral line. This specimen may be distinguished from *Durangites* aff. *rarifurcatus* Imlay (Pl. 17, fig. 9) by coarser ribs, more frequent bifurcation, and stronger ventral tuberculation. *Durangites incertus* Burckhardt

(1912, p. 147, pl. XXXVI, figs. 12-14, 16, 17) has a rounder whorl section, more frequent rib bifurcation, and weaker ventral tubercles.

The larger specimen (Pl. 17, fig. 12) has parts of two outer whorls which probably were a little higher than wide before compression. The complete specimen is not figured. The ribs are high, narrowly rounded at top, broad at base, and separated by wide interspaces. One half of the ribs bifurcate high on the flanks, and most of the simple ribs alternate with short intercalary ribs. No trace of lateral or ventral tubercles is apparent, and only a slight reduction in rib strength occurs along the midventral line.

SPECIMENS: 20105, 20104, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Durangites* beds). Collection K4 in Cañón Alamo, Sierra de Jimulco, Coahuila.

Genus *Substeueroceras* Spath 1923

Substeueroceras subquadratum Imlay, n. sp.

(Plate 15, figures 8, 12-15)

DESCRIPTION: The species is represented by nine immature forms. Shell discoidal, compressed; whorls subquadrate in section, higher than wide, embracing about one-third; flanks on outer whorls flattened, subparallel, rounding abruptly into umbilical wall and fairly abruptly into venter; flanks on inner whorls (Pl. 15, fig. 8) slightly convex and rounding evenly into umbilical wall and venter; venter on outer whorl somewhat flattened, on inner whorl gently convex. Umbilicus fairly narrow and shallow; wall fairly low, oblique on inner whorls, vertical on outer whorls.

The ribs are high, narrow, flexuous, moderately spaced on the inner whorls, becoming rather widely spaced on largest whorl known (Pl. 15, fig. 12). They begin at the line of involution, curve backward on the umbilical wall, incline forward on the flanks, and arch forward slightly on the venter. They are inflected forward near the middle of the flanks and, as in many species of *Substeueroceras*, the inflection becomes accentuated with growth. The mold is marked by a distinct ventral furrow, but the shell shows only a faint thinning of the ribs along the midventral line. The ribbing is characterized at all stages by numerous simple or intercalary ribs which in some specimens are as common as forked ribs. Bifurcation occurs in a zone near the middle of the flanks, although more commonly below than above the middle. No trifurcating ribs have been observed.

Dimensions in mm. are as follows:

Specimen	Diameter	Whorl height	Whorl thickness	Umbilical width
15905	41.0	18.5	14.0	11.5
20053	34.5	15.0	12.5	11.0
20050	19.0	18.5	7.5	5.0

REMARKS: This species may be distinguished from *S. alticostatum* Imlay by its more compressed whorl section, closer-spaced ribbing on its inner whorls, and by its greater number of simple ribs. *S. kellumi* Imlay has finer, closer-spaced ribbing, and fewer simple ribs. The immature form of *S. intercostatum* (Steuer) (1897, p. 46, pl. XXII, figs. 4-5) shows some resemblances but is more involute and has a distinct ventral furrow. *S. incertum* (Steuer) (1897, p. 37, pl. XII, figs. 1-4) has a different whorl section and coarser ribbing. *S.* sp. ind. in Burckhardt (1912, p. 171, pl. XLI, fig. 2) has fewer simple ribs and a different manner of furcation.

TYPE: Holotype 15905, paratypes 20050, 20053, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Substeueroceras* beds). Kellum's collections 1, 5, and 25 in Cañón Alamo, Sierra de Jimulco, Coahuila.

Substeueroceras n. sp. aff. *subfasciatum* (Steuer)

(Plate 15, figure 9)

DESCRIPTION: The species is represented by 18 specimens of which most are small and retain considerable shell material. Shell discoidal, compressed; whorl section ovate on inner whorls, subquadrate on outer whorls, higher than wide, thickest on lower fourth of flanks, embracing about two-fifths; flanks flattened and subparallel below, slightly convex above and converging slightly toward the venter; venter fairly narrow, somewhat flattened. Umbilicus fairly narrow and shallow; wall low and vertical, rounding evenly into flanks.

On the internal mold the ribs are low, rounded, and terminate ventrally at a narrow, smooth ventral furrow. On the shell the ribs are high, thin, fairly widely spaced, and are only slightly reduced in strength along the midventral line. They curve backward on the umbilical wall, curve forward on the lower part of the flanks, recurve backward just above the middle of the flanks, and then curve forward again on the upper part of the flanks and the venter. The ribs are inclined only slightly forward on the inner whorls but anteriorly become more strongly inclined. On the inner whorls most ribs bifurcate near the middle of the flanks, but there are a few simple ribs and rarely an intercalary rib. Anteriorly bifurcation occurs variably below or above the middle of the flanks, and simple and intercalary ribs become a little more common. On the outer whorls many of the bifurcation points are indistinct, and consequently some of the branch ribs are more or less faintly connected. On the largest specimen some of the ribs are trichotomous.

The largest specimens are too poorly preserved to be reproduced, but are several times the size of the specimen figured.

REMARKS: The Mexican species just described probably is new but because of the lack of mature forms it seems advisable at present to merely draw comparisons with similar species. *S. subfasciatum* (Steuer) (1897, p. 47, pl. XIX, figs. 1-3; Gerth, 1925, p. 84, pl. VI, fig. 5, 5a) has similar ribbing but appears to be more evolute and more robust. *S. kellumi* Imlay has denser ribbing on the inner whorls. S. *durangense* (Burckhardt) (1912, p. 168, pl. XL, figs. 5, 7-10) has wider-spaced, more flexuous ribs which are only slightly reduced in strength on the venter.

SPECIMEN: 20033, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Substeueroceras* beds): Kellum's collection 5, Cañón Alamo section, Sierra de Jimulco, Coahuila.

Substeueroceras kellumi Imlay, n. sp.

(Plate 14, figures 1-4)

DESCRIPTION: The species is represented by 14 specimens of which the holotype is the largest. Shell discoidal, compressed; whorl section ovate on inner whorls, subquadrate on outer whorls, higher than wide, thickest on lower fourth of flanks on inner whorls, thickest near middle of flanks on outer whorl of holotype; whorls embracing about two-fifths; flanks flattened and subparallel below, converging slightly above; venter moderate in width on inner whorls, becoming slightly broader on outer whorls, flattened along midline, rounding evenly into flanks. Umbilicus fairly

narrow; wall moderate in height, vertical or slightly overhanging, rounding rather abruptly into flanks. The anterior half of the outer whorl of the holotype probably represents part of the body chamber.

The ribs are flexuous and inclined forward. They curve backward on the umbilical wall, are inflected forward considerably near the middle of the flanks, then recurve slightly and arch forward on the upper part of the flanks and the venter. On the inner whorls to a diameter of about 25 mm. the ribs are thin, fairly high, densely spaced, and commonly bifurcate at or a little above the middle of the flanks. There are a few simple and intercalary ribs. At a greater diameter the ribbing rapidly becomes wider spaced, higher, and broader. Simple ribs become rather common, and trichotomous ribs occur. The outer whorl of the holotype has many tri- and bi-dichotomous ribs. At all stages the ribs on the shell are only slightly reduced in strength along the midventral line although the mold bears a narrow, smooth ventral furrow. At the extreme anterior end of the holotype the flank ribs become broad and somewhat indistinct.

Dimensions in mm. are as follows:

Specimen	Diameter	Whorl height	Whorl thickness	Umbilical width
holotype 15900	114	54(?)	36(?)	27
paratype 20036	31	14.5	11.5	8
paratype 20037	26	13.0	8.5	6.5

REMARKS: This species greatly resembles *Substeueroceras lamellicostatum* (Burckhardt) (1912, p. 167, pl. XL, figs. 1-4, 6) but has wider-spaced ribbing on the outer whorls, fewer intercalary ribs, and probably a slower rate of coiling. It is distinguished from the forms described in this report as *S.* aff. *subfasciatum* (Steuer) by much closer-spaced ribs on the inner whorls and by thicker, rounder ribs on the outer whorls. *S. koeneni* (Steuer) (1897, p. 45, pl. XVII, figs. 1-5) is much like *S. kellumi* Imlay but, judging from published figures, appears to have finer, more flexuous ribbing on its outer whorls, a more pronounced ventral groove on its inner whorls, and is a little more involute. *S. steueri* (Gerth) (1925, p. 86, pl. V, figs. 4, 4a) has a more robust form and closer-spaced ribbing on its outer whorls.

TYPE: Holotype 15900, paratypes 20036, 20037, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Substeueroceras* beds). Kellum's collections 1, 5, and 25 in Cañón Alamo, Sierra de Jimulco, Coahuila.

Substeueroceras alticostatum Imlay, n. sp.

(Plate 15, figures 1-7)

DESCRIPTION: The species is represented by about 24 specimens and probably includes several large fragments of outer whorls which have very coarse ribbing.

Shell discoidal; inner whorls ovate in section, wider than high; outer whorls becoming subquadrate in section, higher than wide, embracing about two-fifths; flanks of outer whorls nearly flattened below, rounding above into moderately broad venter which is somewhat flattened along its median line. Umbilicus fairly narrow and deep; wall fairly high, vertical at base, rounding rather abruptly into flanks.

The innermost whorls (Pl. 15, figs. 5, 6) bear high, narrow, widely spaced ribs which curve backward on the umbilical wall, incline forward on the flanks, and cross the venter transversely. They undergo only faint diminution in strength along

the midventral line. Most ribs bifurcate near the middle of the flanks but there are four or five simple ribs per whorl.

The ornamentation of the outer whorls is like that of the inner. The ribs remain high, narrow, and widely spaced. In addition they are more or less inflected forward near the middle of the flanks and arch forward slightly on the venter. Simple ribs and intercalary ribs are rare. Bifurcation occurs commonly a little above the middle of the flanks. All the ribs are simple on the umbilical edge, and no examples of tri- or bi-dichotomy have been observed. A ventral furrow is present on the internal mold, but on the shell the ribs are only slightly reduced in strength.

The anterior end of the outer whorl of the holotype is slightly drawn away from the inner whorls. At a diameter of 35 mm., the whorl height is 17 mm., the whorl thickness 15 mm., and the umbilical width 10 mm.

REMARKS: This species is easily distinguished from the Mexican species described herein by its coarse and widely spaced ribs. *S. santarosanum* (Burckhardt) (1906b, p. 129, pl. XXXV, figs. 1-4) has a wider, shallower umbilicus, and a greater number of simple ribs. *S. disputabile* (Castillo and Aguilera) (1895, p. 14, pl. XIV, fig. 1) has a greater resemblance but is distinguished by the mode of rib-branching on its outer whorl.

TYPE: Holotype 15906, paratypes 20056, 20055, 20086, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Substeueroceras* beds). Kellum's collections 1, 5, 25, and 26 in Cañón Alamo, Sierra de Jimulco, Coahuila.

Genus *Berriasella* Uhlig 1910

Berriasella zacatecana Imlay, n. sp.

(Plate 18, figures 4, 7-10)

DESCRIPTION: Shell discoidal, flattened; outer whorl subquadrate in section, higher than wide, thickest at lower third of flanks, embracing slightly less than two-fifths; flanks nearly flat, converging slightly toward venter; venter fairly broad, flattened. Umbilicus fairly wide and shallow; wall moderately high, nearly vertical, rounding evenly into flanks. Body chamber represented by one-third of the outer whorl of holotype.

The inner whorls bear pronounced, moderately spaced ribs which start low on the umbilical wall, incline forward slightly on the flanks, and bifurcate just ventral of the line of involution of the succeeding whorl. On the outer whorl the ribs are flexuous, strong, and terminate ventrally in tubercles which bound a fairly broad, smooth, midventral area. They begin near the middle of the umbilical wall, curve backward to the edge of the umbilicus, are inflected forward considerably on the middle of the flanks, recurve backward on the upper parts of the flanks, and curve forward again at the ventro-lateral margins. They are strongest on the lower parts of the flanks and are highest at the points of bifurcation. Most ribs bifurcate at or near the middle of the flanks, but some bifurcate on the upper third or the lower third. There are a few simple ribs. Constrictions are not present, although some interspaces are wider than others. The suture line is poorly preserved.

Near the anterior end of the holotype (Pl. 18, figs. 4, 7, 8), the whorl height is 23 mm., the whorl thickness 17.5 mm., and the umbilical width is 20 mm.

REMARKS: This species greatly resembles *Berriasella calisto* (d'Orbigny) (1842-

1851, p. 551, pl. 213, figs. 1, 2; Burckhardt, 1919, p. 56, 1921, pl. 19, figs. 1, 2) but has a wider whorl section and coarser, more distantly spaced ribs. *Berriasella oppeli* Kilian (1889, p. 662; Zittel, 1868, p. 107, pl. 20, figs. 1-4) has less flexuous ribs and bifurcation occurs higher on the flanks.

TYPE: Holotype 19295, paratype 19293, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Caja formation (*Substeueroceras* beds). Bed 15, collection 3, of Imlay's section on the north side of Cañón del Toboso, Sierrita del Chivo, near Symón, Durango.

Berriasella? sp.

(Plate 5, figures 5, 6, 9)

REMARKS: Under this heading are included immature forms of several distinct species which are close to *Berriasella* and are associated with *Substeueroceras* in the Cañón Alamo section of the Sierra de Jimulco.

The form shown on Plate 5, figures 5 and 6 (20042), shows coarse, widely spaced, nearly regularly biplicate ribbing which is only slightly interrupted on the venter. The ribs are somewhat swollen at the furcation points and on the venter. The inner whorls are much wider than high; the outer whorl is only slightly wider than high. The combination of forwardly inclined secondary ribs, of increasing whorl height with growth, and swellings at the ribs' furcation points, perhaps indicates a position nearer *Aulacosphinctes* than *Berriasella* or *Micracanthoceras*.

The form shown on Plate 5, figure 9 (20041) probably belongs to *Berriasella*. The whorl section is as wide as high. The outer whorl embraces about two-fifths of the preceding whorl. The ribs are nearly regularly biplicate, and the secondaries incline strongly forward. The ribs pass ventrally into swellings but are only slightly reduced in strength along the midventral line, although the internal mold bears a distinct groove.

Another form, shown on Plate 10, figures 8 and 9 (20039), has very distinctive ornamentation on its outer whorl. Its ribs are irregularly spaced on the umbilical edge; some arise close together, others arise in pairs. All ribs bifurcate a little above the middle of the flanks, and the secondaries arch forward on the venter which they cross without diminution in strength. The outer layer of shell is lacking except at the anterior end of the specimen, but this fragment shows that the ribs are high and thin. The bifurcation points are slightly swollen, but rib swellings are not indicated on the venter.

SPECIMEN: 15907, 20039, 20041, 20042, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Substeueroceras* beds). (1) Specimen 15907 from Kellum's collection 25 in Cañón Alamo. (2) Other forms from Kellum's collection 5 in Cañón Alamo, Sierra de Jimulco, Coahuila.

Berriasella? *coahuilensis* Imlay, n. sp.

(Plate 16, figures 1-7)

DESCRIPTION: The species is represented by four specimens which retain part of the shell material. The largest specimen is sutured to near the anterior end.

Shell medium in size, discoidal; whorl section of outer whorls subrectangular, higher than wide, becoming relatively higher and narrower during development; whorl sec-

tion of inner whorls subovate, slightly higher than wide; greatest thickness of whorl section near middle of flanks except at anterior end of types where it occurs near the umbilical edge; outer whorls embracing nearly three-fourths; flanks convex on inner whorls, becoming broader and flatter during development, nearly flattened on anterior end of outer whorl; venter truncated, moderate in width, becoming slightly convex at anterior end of shell. Umbilicus fairly narrow and deep; wall low and vertical on inner whorls, moderately high and slightly overhanging on outer whorls.

The innermost known whorls (Pl. 16, fig. 1) possess mainly simple ribs which start on the umbilical wall and pass nearly radially across the flanks but curve forward somewhat near the venter which they cross transversely with slight diminution in strength. They possess prominent, rounded tubercles at the edge of the venter, and some are faintly swollen near the middle of the flanks. Bifurcation occurs rarely and only on the lower parts of the flanks. Several of the wider interspaces possibly represent constrictions.

On the outer whorls the ribs begin low on the umbilical wall, curve backward slightly to the edge of the umbilicus, incline forward on the flanks in a flexuous manner, and are weakly arched forward on the venter. The ribs are low, rounded, and about as broad as the interspaces. They increase gradually in strength ventrally and undergo only slight diminution along the midventral line. On the posterior ends of the outer whorls of the large specimens most of the ribs are simple, but there are examples of bi- and trichotomy on the lower half of the flanks. On the anterior end of the outer whorl simple ribs are about one-fourth as common as forked ribs, and bifurcation occurs at various heights from the edge of the umbilicus to the upper third of the flanks. In the case of bifurcation near the umbilical edge, one or both branches bifurcate again higher up. Generally the bifurcation points are indistinct. Short intercalary ribs occur rarely.

Dimensions in mm. are as follows:

Specimen	Diameter	Whorl height	Whorl thickness	Umbilical width
holotype 15901	63	32	20(?)	13
paratype 20032	53	27	18(?)	12

REMARKS: The affinities of this species are probably nearer to the berriasellids than to the neocomitids as indicated by the absence of umbilical tubercles, the forward arching of the ribs on the venter, and the rib curve. It bears considerable resemblance to the Californian forms described by Stanton (1895, p. 79-80, pl. XVII, figs. 1, 2; pl. XVIII, fig. 5; pl. XVIII, figs. 3, 4) as *Hoplites storrsi* and *H. angulatus* but is readily distinguished by its greater involution and by many details of ornamentation. Resemblances also exist with some species described by Gerth from the *Substeueroceras* beds of Argentina. *Thurmannites duraznensis* Gerth (1925, p. 97, pl. IV, figs. 1, 1a) is less involute than the Mexican species and has finer, wider-spaced ribbing. *Thurmannites? discoidalis* Gerth (1925, p. 98, pl. V, figs. 3, 3a) is difficult to compare because of the difference in size but is more evolute, more compressed, and has a smooth midventral area.

TYPE: Holotype 15901, paratypes 20032, 20031, 20030, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Substeueroceras* beds). Kellum's collection 25 in Cañón Alamo, Sierra de Jimulco, Coahuila.

Genus *Proniceras* Burckhardt 1919

Proniceras jimulcense Imlay, n. sp.

(Plate 18, figures 1-3)

DESCRIPTION: Form discoidal, flattened; outer whorl ovate in section, higher than wide, embracing preceding whorl slightly more than one-half; flanks nearly flat below, slightly convex above; venter arched. Umbilicus fairly wide, moderate in depth; wall moderately high, steeply inclined, rounding rather abruptly into flanks at anterior end of outer whorl, rounding evenly at posterior end.

The inner whorls bear strong, wide, irregularly spaced ribs which start at the line of involution and incline slightly forward on the flanks. Most of the ribs are simple, but some bifurcate low on the flanks. Umbilical tubercles appear at a diameter of about 44 mm. and become gradually stronger anteriorly.

On the outer whorl the ribs begin faintly near the line of involution, incline slightly backward to the umbilical shoulder, and terminate in stout, radially elongated tubercles. From the tubercles pass bundles of two or three ribs which bifurcate just above the tubercles, or near the middle of the flanks. The ribs are low, broad, and somewhat indistinct on the lower parts of the flanks, but become stronger above and cross the venter without diminution in strength. They incline forward considerably on the lower part of the flanks and strongly on the venter. Constrictions are narrow, fairly shallow, and most conspicuous on the inner whorls.

The extreme anterior end of the holotype has been crushed, but the remainder of the shell seems nearly undeformed except for slight depression. Remnants of shell attached to the left side and venter of the outer whorl indicate the former presence of a nearly complete whorl beyond the present outer whorl. The shell remnants show that the tubercles become larger and blunter anteriorly and that the ribs are replaced by striae which in turn are replaced by smooth shell.

At a diameter of 77 mm. the whorl height is 28 mm., the whorl thickness 22 mm., and the umbilical width 28 mm.

REMARKS: This species is very close to *P. subpronum* Burckhardt (1919, p. 48; 1921, pl. XVI, figs. 9-15, 20-22, 26, 28-30, 32, 34, 35) but is more involute, has a narrower umbilicus, a higher whorl section, stouter tubercles, broader ribs which are more inclined forward, shallower constrictions, and on the outer whorls the ribs become obscure on the lower part of the flanks.

TYPE: Holotype 15899, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Substeueroceras* beds). Kellum's collection 25 in Cañón Alamo, Sierra de Jimulco, Coahuila.

Proniceras scorpionum Imlay, n. sp.

(Plate 18, figures 5, 6)

DESCRIPTION: Form discoidal, flattened; whorls enlarging slowly, ovate in section, higher than wide, thickest near middle of flanks, embracing about one-fourth; flanks nearly flat; venter slightly sharpened at posterior end of outer whorl, narrowly rounded at anterior end. Umbilicus fairly wide, shallow; wall extremely low, rounded.

On the inner whorls the ribs are strong, straight, and inclined slightly forward. Most ribs are simple, but some bifurcate near the middle of the flanks. The outer whorl, preserved mainly as an internal mold, bears fine, slightly flexuous ribs which are moderately spaced. The ribs originate at the line of involution and incline obliquely forward to the middle of the flanks where they give rise to two or three

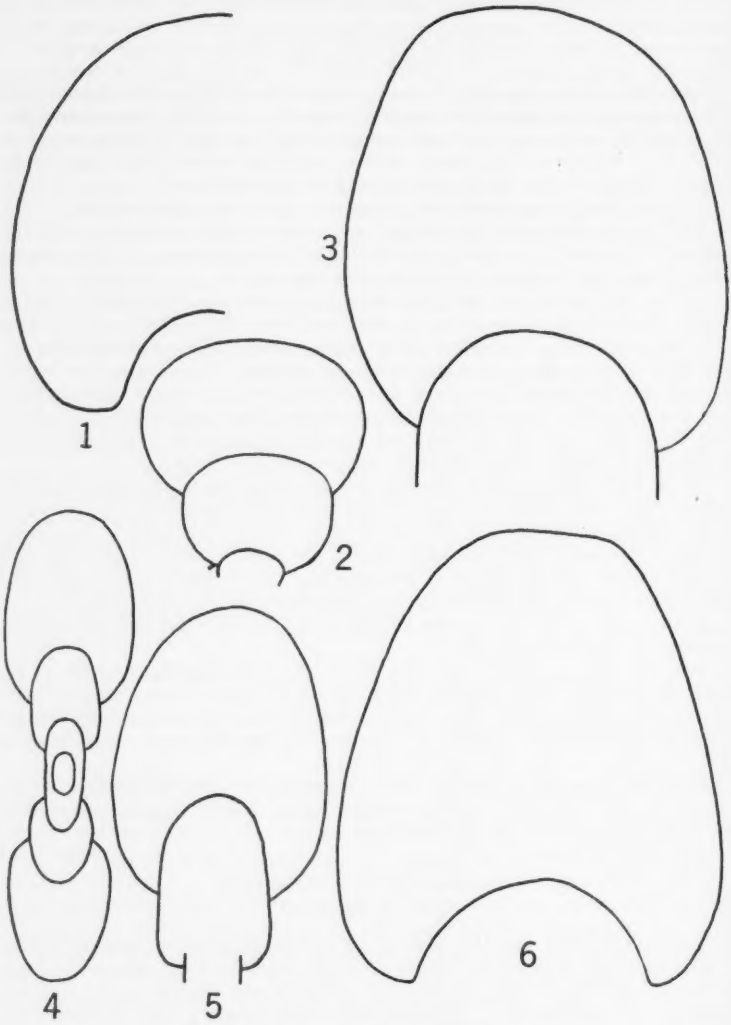


FIGURE 7.—*Whorl sections of ammonites*

(1) *Subplanites?* sp. (U. M. 19546); (2) *Subdichotomoceras?* sp. (U. M. 16979); (3) *Indosphinctes?* sp. (U. M. 19307); (4) *Idoceras striatum* Imlay (U. M. 19492); (5) *Indosphinctes?* sp. (U. M. 15960) at anterior end; (6) *Indosphinctes?* sp. (U. M. 19400) at posterior end.

slightly weaker secondary ribs which incline forward less strongly. One of the trifurcating ribs is generally loosely connected with the primary rib. There are a few intercalary ribs. The ribs form chevrons on the posterior part of the outer whorl but on the anterior part are merely weakly curved forward. Each whorl has four or five fairly strong constrictions.

Greatest diameter of holotype 34 mm.; height of whorl, 10 mm.; thickness of whorl, 8.5 mm.; width of umbilicus, 16 mm.

REMARKS: This species greatly resembles *P. idoceroides* Burckhardt (1919, p. 42; 1921, pl. XV, figs. 2-4) but has wider-spaced ribs, stronger constrictions, and on the outer whorl its primary ribs branch consistently near the middle of the flanks.

TYPE: Holotype 19408; paratype 19406, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Caja formation (*Substeueroceras* beds). Fossils from black limestone nodules in lower part of 25-foot unit of whitish gray, platy limestone at top of Jurassic section, Cañón del Escorpión about 3 miles northeast of Melchor Ocampo, Zacatecas.

Proniceras aff. *pronum* (Oppel)

(Plate 1, figures 8, 9)

DESCRIPTION: One fragment shows considerable resemblance to *Proniceras pronum* (Oppel) as figured by Djanelidze (1922, p. 70, pl. II, figs. 3a, b). The section is spheroidal and is as wide as high. The umbilical tubercles are strong, elongated radially, and are widely spaced. Each tubercle gives rise to three or four ribs which incline forward. In addition there are one or two intercalary ribs between successive rib bundles. The ribs are weakened a little on the venter and form broad chevrons.

SPECIMEN: 19184, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Substeueroceras* beds). Kellum's collection 5 in Cañón Alamo, Sierra de Jimulco, Coahuila.

Proniceras sp.

(Plate 1, figure 7; Plate 7, figure 8)

REMARKS: Several fragmentary specimens from Sierrita del Chivo are mentioned because of their stratigraphic significance. One immature form (Pl. 7, fig. 8) possibly belongs to *Proniceras subpronum* Burckhardt (1919, p. 48; 1921, pl. XVI, figs. 9-15, 20-22, 26, 28-30, 32, 34, 35). Another specimen (Pl. 1, fig. 7) is considerably weathered but resembles *P. idoceroides* Burckhardt (1919, p. 42; 1921, pl. XV, figs. 2-4).

SPECIMENS: 19428, 19430, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Caja formation (*Proniceras* beds): Bed 15 (Collection 5) of Imlay's section on the north wall of Cañón Toboso, Sierrita del Chivo, near Symón, Durango.

Genus *Aegocrioceras* Spath 1924

"Aegocrioceras" sp.

(Plate 11, figures 1, 2)

DESCRIPTION: One fragment is provisionally placed under *Aegocrioceras* although probably belonging to a new genus. Spiral probably open; whorl ovate in section, higher than wide, thickest near middle, enlarging slowly; flanks gently convex, rounding rather abruptly into flattened dorsum, rounding gently into venter. All ribs are simple. They are high on the flanks, strongest at the edge of the venter, slightly reduced in strength along the midventral line, and nearly vanish on the dorsum. They trend backward slightly on the dorsum, forward slightly on the flanks,

and cross the venter nearly transversely, or arched a little forward. Most of them are nearly straight on the flanks, but some are inflected forward near the middle. The interspaces are wide but variable and have flat bottoms.

SPECIMEN: 20038, Museum of Paleontology, University of Michigan.

OCCURRENCE: La Casita formation (*Substeueroceras* beds). Collection K5 in Cañón Alamo, Sierra de Jimulco, Coahuila.

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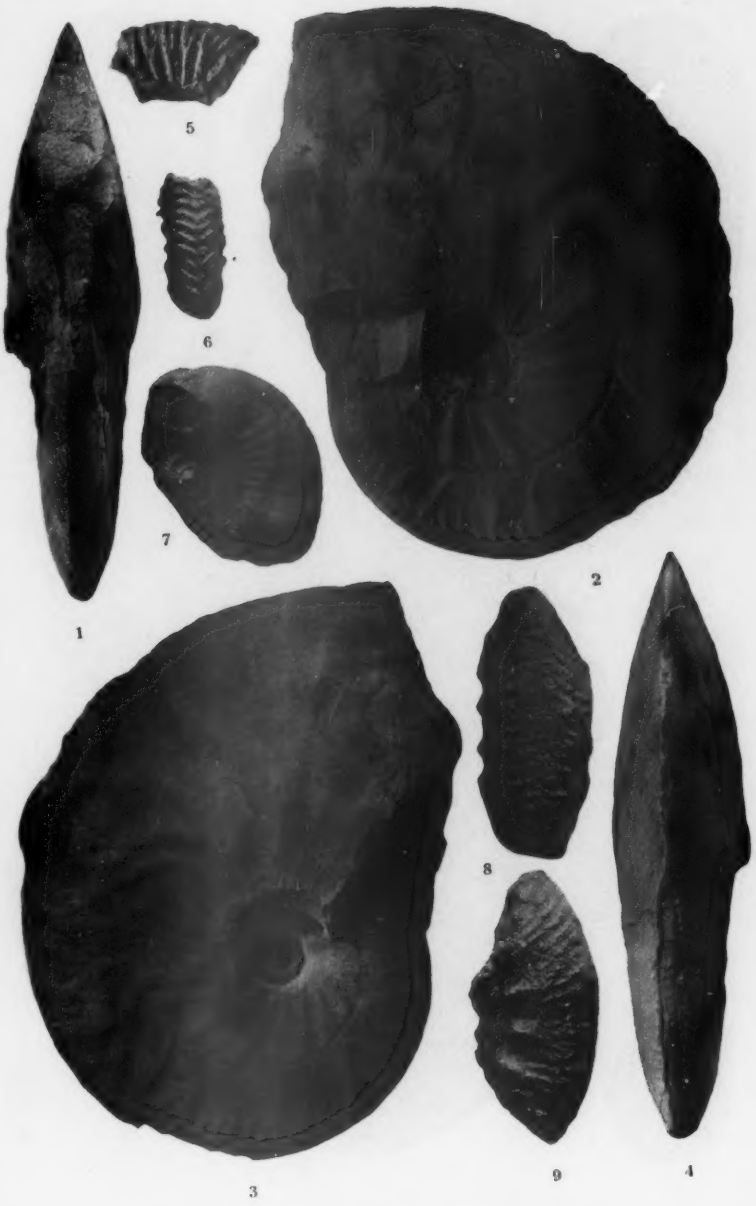

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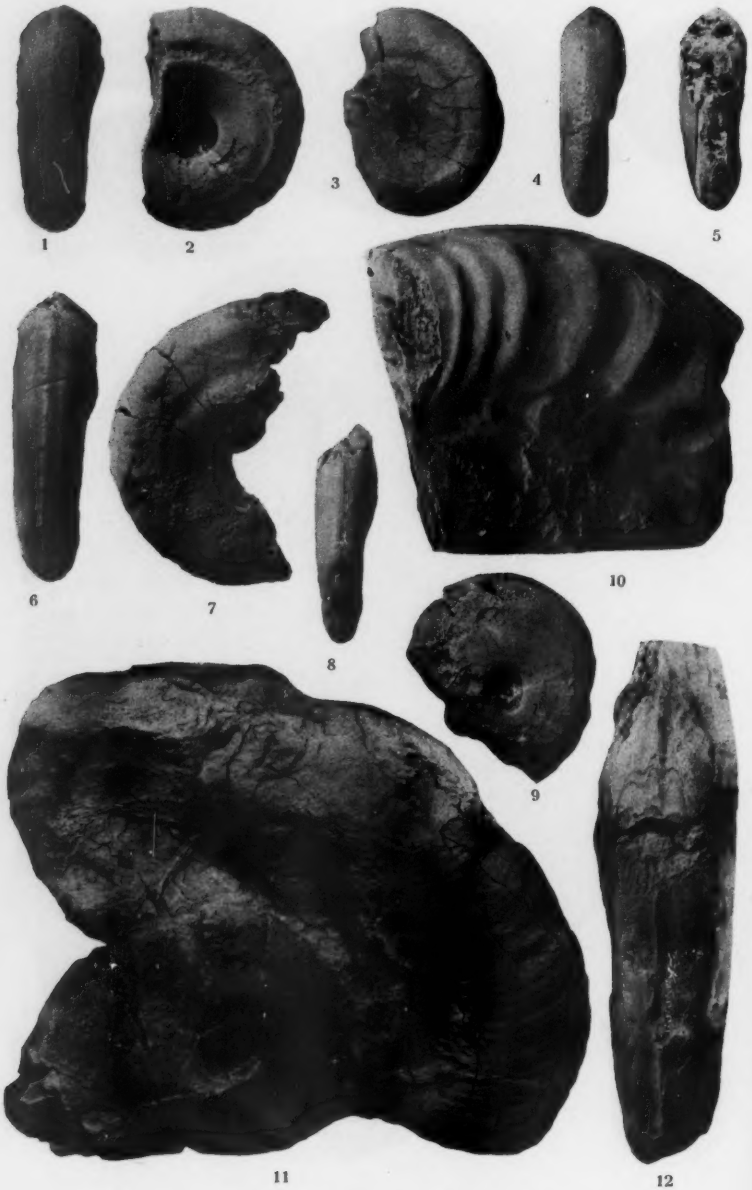

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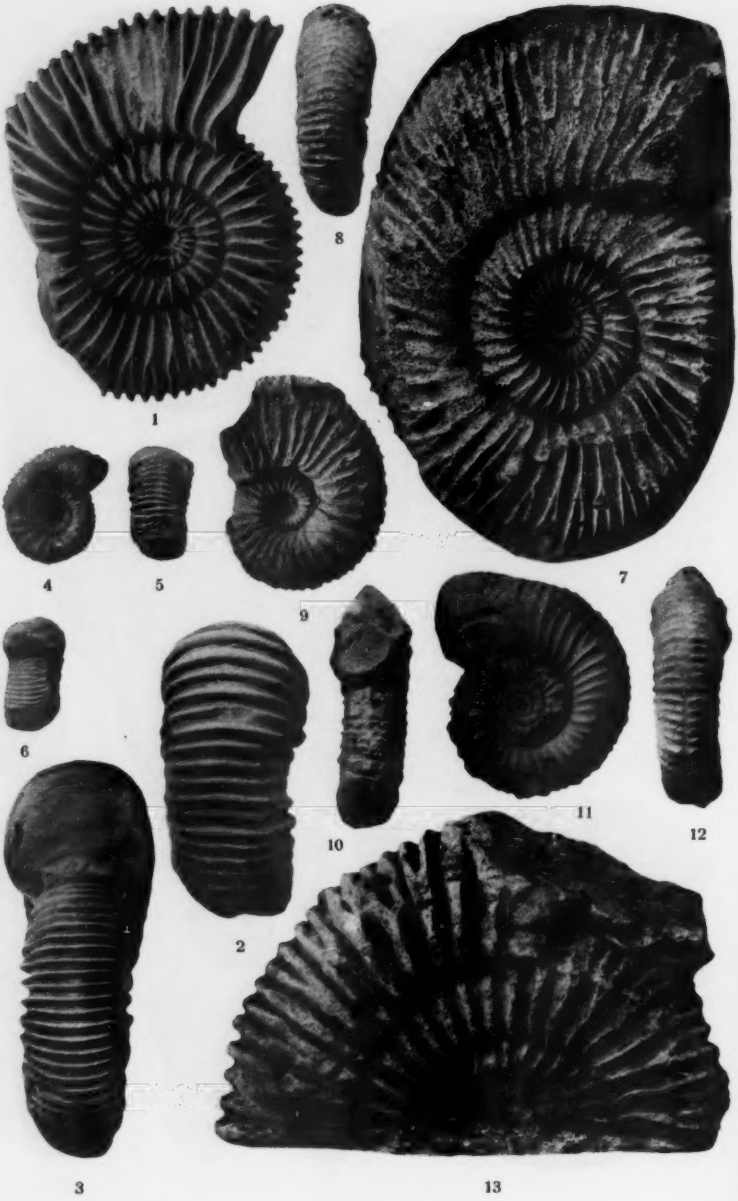

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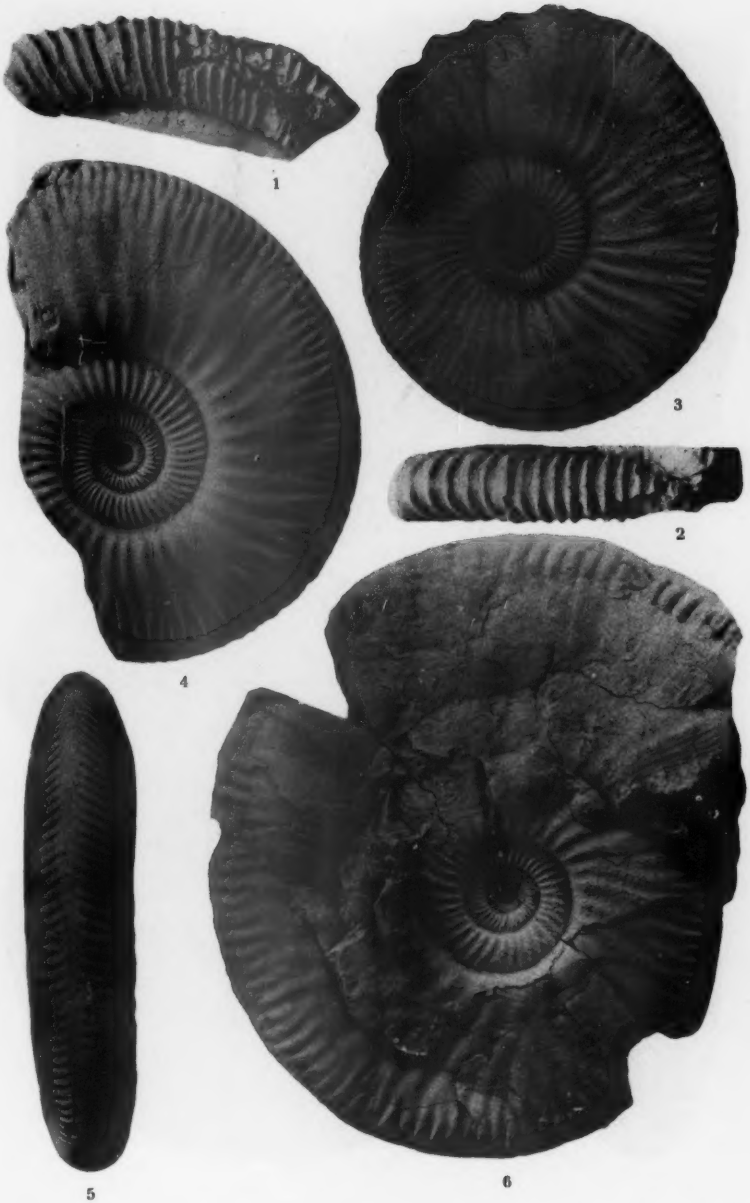

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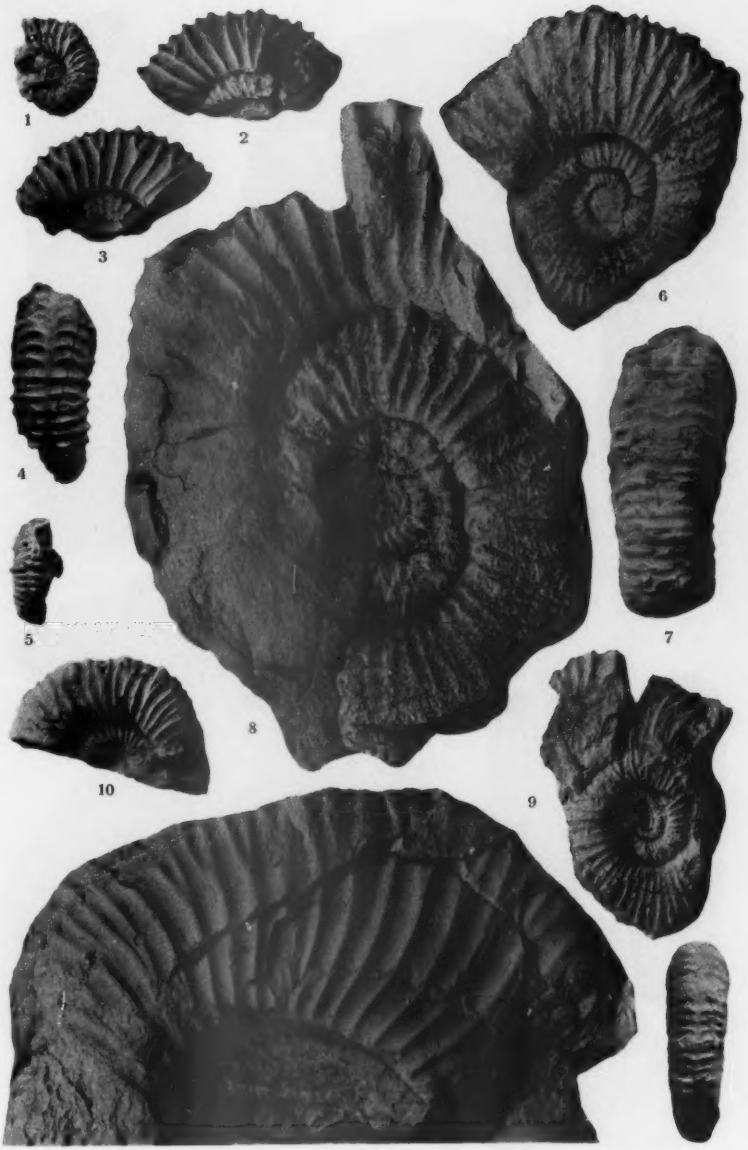

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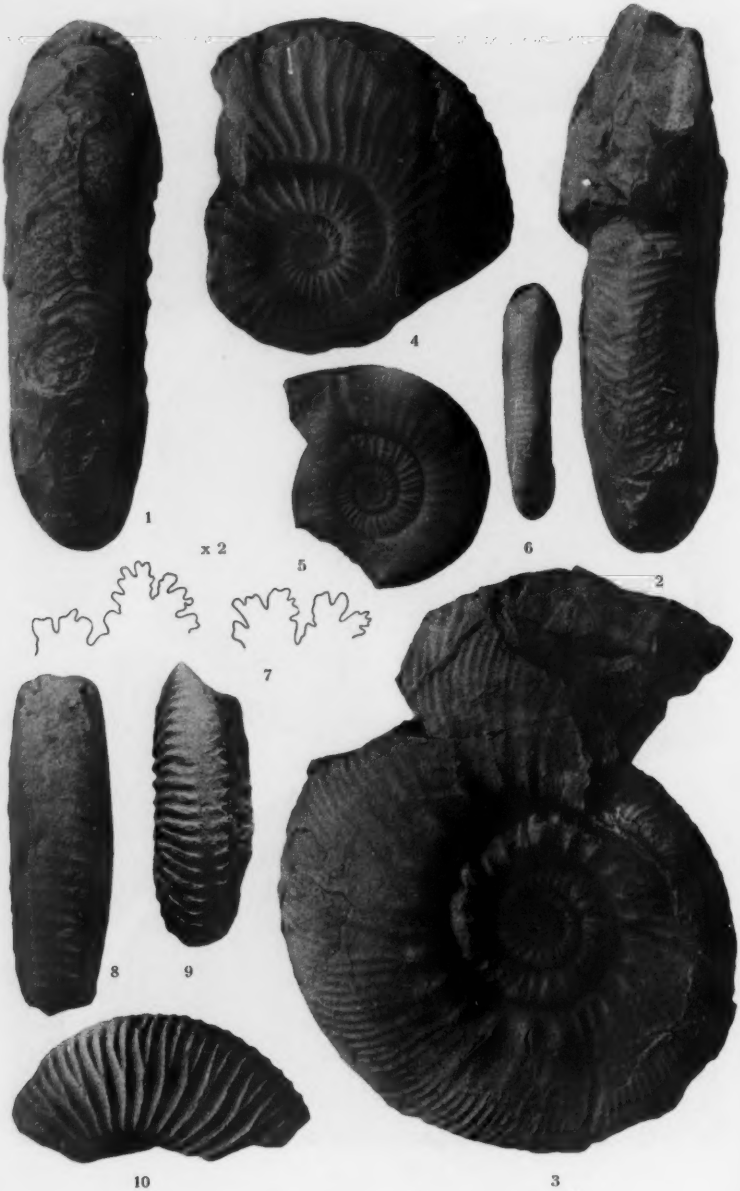

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DEVONIAN FOSSIL ZONES IN WELLS FROM SOUTHWESTERN ONTARIO

BY MADELEINE A. FRITZ

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ABSTRACT

A systematic study of the cuttings from a number of oil and gas wells located in southwestern Ontario has led to the establishment of a number of reliable horizons based upon microfossils.

Graphs have been prepared to show the consistency of the relationships of these horizons in several of the well-known fields. A graphic comparison has also been made between the fossil horizons and the physical horizons commonly used by the well drillers.

The investigation has shown that the top of the Big Lime, a physical horizon used by the well drillers, is invalid at least in the Dawn field. Furthermore, it has been demonstrated that another physical horizon—the bottom of the Big Lime—is present which may be relied upon more generally.

INTRODUCTION

Very early in the history of geological science in North America the Devonian was studied in both Ontario and New York, and considerable knowledge of the fauna was acquired by many able workers including

Hall, Conrad, Billings, Nicholson, and Dawson. Almost of necessity at that time the greater part of the work was confined to a study of the macrofossils, with only a limited consideration of the microfossils. It has been known for some time that there is a large assemblage of micro-

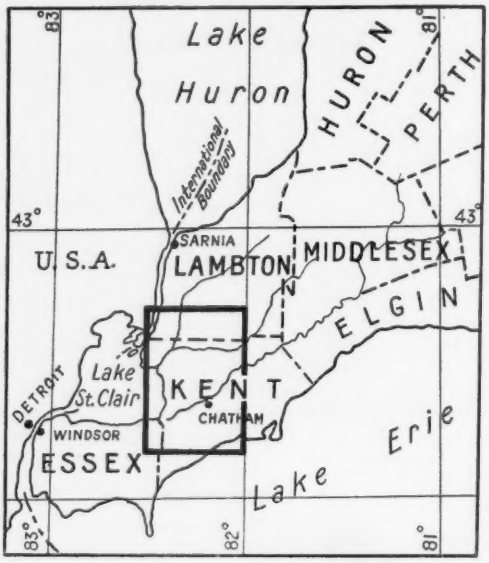

FIGURE 1.—*Part of the Ontario peninsula*
Showing location of figure 2.

organisms, both plant and animal, and recently more attention has been paid to these interesting forms. Especially have they been of interest in the stratigraphy of petroleum geology since these minute fossils have escaped the drastic treatment to which the rock was subjected by the well-driller's tools.

In the summer of 1935 the Geological Survey of Canada undertook a systematic study of the cuttings from a number of wells in southwestern Ontario in order to determine whether horizons based upon microfossils might be established in this area. The material was assembled by Dr. C. S. Evans, who initiated the work at Ottawa. For the preparation of this paper the Survey of Canada has kindly given the writer permission to make use of the information obtained from a study of this material.

OUTLINE OF WORK

The study was limited to a consideration of the microfossils from certain wells in Kent and Lambton counties. The wells in these counties are grouped in a number of fields; the fields to be considered here are the D'Clute, Dawn, and Dover, with a brief reference to the East Tilbury. This investigation has shown that the Devonian strata may be subdivided into several well-defined fossil zones. The recognition of these zones has led to the establishment of more reliable horizons than have been known hitherto in this gas and oil region of Ontario.

The drillers have been accustomed to use a physical horizon—the top of the Big Lime—as a marker to indicate deeper structures. By the Big Lime is meant the sequence of limestone beds comprising the Delaware and Onondaga formations. The reliability of the Big Lime as an horizon has been questioned because it varies in character and thickness in the well-known fields under discussion. For example, in the D'Clute field it is generally considered that the Delaware and Onondaga are separable physically into two units, the combined thickness of which approximates 200 feet. The Delaware consists of a fine- to coarse-grained light-buff to gray crinoidal limestone. The Onondaga is a cream to light-buff limestone with some quartz at the bottom. In places this limestone is granular owing to the development of dolomite crystals. In the Dover field the total thickness of the Big Lime is apparently about the same as in the D'Clute, but there does not appear to be any significant difference in the lithology between the upper beds which belong to the Delaware and lower beds which are Onondaga. In this field a more uniformly gray-buff limestone constitutes the whole unit. In the Dawn field there is only about 100 feet of Big Lime, and lithologically it is similar to the Onondaga of the D'Clute, thus suggesting that the Delaware might be absent in that field.

As a result of this study one fossil horizon has been established in the Huron shale, three horizons in the Hamilton formation, one in the Delaware, and two near the base of the Onondaga. The establishment of these horizons has afforded a means of checking the top of the Big Lime as a reliable marker.

From this fossil evidence it would seem that in the Dover and D'Clute fields the top of the Big Lime bears a consistent relationship to the fossil zones and, in these two fields, may be regarded as a valid horizon. In the Dawn field, however, the situation is rather anomalous. In this last-mentioned field material from only three wells was examined and in only one of these was the Delaware fossil zone recognized. According to figures the top of the Big Lime in this field is at least 25 feet below this fossil zone. Since, as stated, the Delaware fossil zone is present, it is obvious

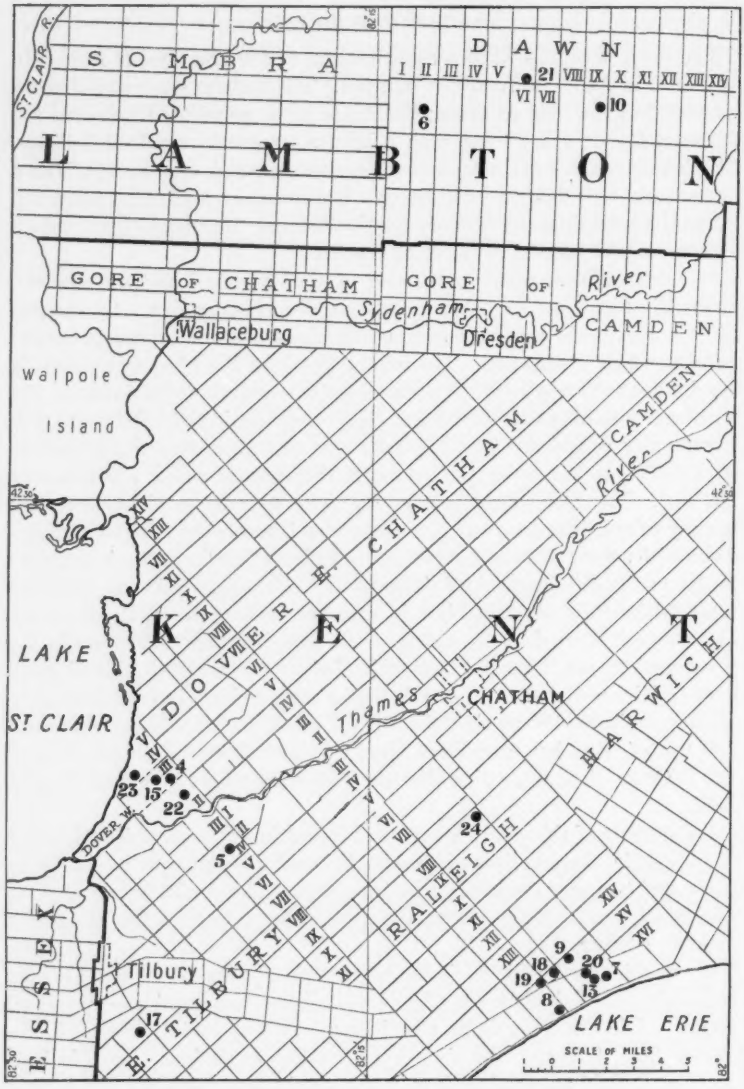

FIGURE 2.—*Wells in Kent and Lambton counties*

that this formation is not absent in the Dawn field as previously suggested. It is probable that the Big Lime, as recognized in this field, includes only Onondaga beds. Furthermore, although in the Dawn field the limestone is relatively thin, the total thickness of strata between the bottom of the Big Lime and the upper fossil zone of the Hamilton is approximately the same as in the Dover and the D'Clute. This would seem to substantiate the belief that the Delaware is not missing. Hence it would seem more reasonable to postulate that the Delaware, rather than being absent in the Dawn field, is represented by another type of sediment, probably by a shale similar to that of the Hamilton formation; such a unit would be less readily distinguished than the heavy limestone in drilling.

It is thus seen that the top of the Big Lime is not uniform in this section of Ontario and, consequently, is not a reliable horizon.

Having abandoned the top of the Big Lime as an horizon the writer considered the possibility of using the bottom of this physical unit as a marker. From the top of the upper fossil zone of the Hamilton to the bottom of the Big Lime the thickness of the strata in all the fields shows consistent relationships. In the Dawn area the thickness averages 345 feet, in the Dover 338 feet, in the D'Clute 260 feet, and in the East Tilbury 190 feet. Furthermore, in all the wells the bottom of the Big Lime bears a fairly consistent relationship to each of the recognized fossil zones. In view of this evidence, therefore, it would seem reasonable to use the bottom of the Big Lime, in these fields, as a dependable horizon of reference.

FOSSIL ZONES

During the course of this study the following microfossil horizons were established:

Upper Spore zone; Upper Ostracode zone; Pteropod zone; Bryozoa zone; Lower spore zone; *Trochiliscus* zone; and Lower Ostracode zone.

DESCRIPTION OF FOSSIL ZONES

UPPER SPORE ZONE

This zone occurs in the Huron shale of the Upper Devonian. It is characterized by a profusion of minute, chitinous, flattened, disk-shaped bodies, supposedly of plant origin, suggestive of spores or structures related to spores. These fossils extend through 150 feet of black, bituminous shale. They are referred here to the species *Protosalvinia huronensis* (Dawson, 1886). Unfortunately, this zone was recognized only in the wells of the Dawn field, but its position in these wells bears a distinct relationship to the fossil horizons beneath it.

UPPER OSTRACODE ZONE

This is a particularly well marked horizon extending throughout the bluish-gray calcareous shales of the Hamilton formation; these shales attain a thickness in certain wells of approximately 100 feet. The zone is characterized by an abundance of the well-defined and splendidly preserved ostracode *Ponderodictya punctulifera* (Hall). This species is subject to much variation with respect to the spines and tubercles that ornament the surface of the valves. It was recognized in large numbers in all the fields and in practically every well from which samples were examined. The same form has been recorded from surface exposures of the Widder beds near Arkona, Ontario (Stauffer, 1915; Coryell and Malkin, 1936); from the Silica shale of northwestern Ohio (Stewart, 1936); from the Wanakah shale, New York (Warthin, 1934); and from the Bell shale of Michigan (Van Pelt, 1933). In view of the excellent preservation, abundance, restricted geological range, and widespread geographical distribution, this species is considered to be an excellent upper Middle Devonian index microfossil.

Associated with this species in the wells under consideration is a large assemblage of ostracodes not yet specifically determined; these mark a very persistent and restricted horizon.

PTEROPOD ZONE

This zone occupies approximately the same stratigraphic position as the upper ostracode zone. The abundance of these microorganisms, however, warrants the separation into a special zone. *Styliolina fissurella* (Hall) is the most abundant and characteristic species, but associated with it are several other pteropods including *Tentaculites attenuatus* Hall, *T. bellulus* Hall, *T. gracilistriatus* Hall, and *Coleolus tenuicinctus* Hall.

BRYOZOA ZONE

The bryozoan zone, like the upper spore zone, is restricted to the wells in the Dawn field. It occurs near the base of the Hamilton shales and is represented by isolated fragments of the easily recognizable genus *Sulcoretepora*. From such small fragments of the zoarium as are here preserved, a specific identification is attended with considerable difficulty; they have been tentatively referred, however, to the species *S. incisurata* (Hall). The form occurs in each of the three Dawn wells, and its curve of occurrence is in accordance with those of the other zones.

LOWER SPORE ZONE

Minute chitinous fossils in the form of disks or globes a quarter of a millimeter or less in diameter characterize this zone which occurs in the Delaware limestone. These fossils are particularly well represented in

TABLE 1.—*Position of fossil zones and Big Lime in wells*

Name of well	I Upper Spore (middle of zone)		II Upper Ostracode		III Pteropod		IV Bryozoa		V Top Big Lime		VI Lower Spore		VII Trochiliscus		VIII Lower Ostracode		IX Bottom Big Lime		Elevation of surface
	Depth in well	Elevation A.M.T.	Depth in well	Elevation A.M.T.	Depth in well	Elevation A.M.T.	Depth in well	Elevation A.M.T.	Depth in well	Elevation A.M.T	Depth in well	Elevation A.M.T.	Depth in well	Elevation A.M.T.	Depth in well	Elevation A.M.T.	Depth in well	Elevation A.M.T.	A.M.T.
Tilbury Field																			
Eugene Coste 6 (17)	.....	.....	220	375	190	405	.....	.....	290	305	.....	.....	.....	.....	380	215	410	185	595
Dover Field																			
Union 18 (23)	.....	.....	.....	.....	.....	.....	.....	.....	260	316	300	276	.....	.....	.....	.....	430	146	576
Union 19 (15)	.....	.....	100	477	100	477	.....	.....	255	322	.....	.....	.....	.....	.....	.....	445	132	577
Uunion 14 (4)	.....	.....	120	457	110	467	.....	.....	250	327	.....	.....	.....	.....	320	257	460	117	577
Union 17 (22)	.....	.....	.....	.....	.....	.....	.....	.....	290	284	300	274	.....	.....	.....	.....	460	114	574
Dauphin Imperial 2 (5)	.....	.....	90	500	90	500	.....	.....	250	340	410	180	.....	.....	.....	.....	.....	.....	590
D'Clute Field																			
D'Clute 14 (8)	.....	.....	190	459	200	449	.....	.....	269	380	380	269	.....	.....	450	199	465	184	649
Un. D'Cl. Ron. 11 (19)	.....	.....	.....	.....	270	373	.....	.....	275	368	320	323	430	213	450	193	440	203	643
Olga 3 (24)	.....	.....	200	393	200	393	.....	.....	270	323	340	253	380	213	440	153	430	163	593
Un. D'Cl. Sykes 12 (18)	.....	.....	200	443	190	453	.....	.....	275	368	340	303	450	193	450	193	440	203	643
D'Clute 19 (9)	.....	.....	210	433	210	433	.....	.....	260	383	.....	.....	410	233	370	273	430	213	643
Un. D'Cl. Storey 15 (20)	.....	.....	190	453	190	456	.....	.....	260	386	320	326	.....	.....	460	183	440	206	646
Moore 26 (13)	.....	.....	190	456	190	456	.....	.....	275	371	.....	.....	.....	.....	.....	.....	460	186	646
Lathwaite 24 (7)	.....	.....	200	446	190	456	.....	.....	310	336	.....	.....	.....	.....	.....	.....	475	171	646
Dawn Field																			
Union 61 (6)	160	466	220	406	315	311	270	356	475	151	.....	.....	.....	.....	.....	.....	585	41	626
Union 2 (21)	150	506	240	416	240	416	290	366	.....	.....	380	276	.....	.....	.....	.....	.....	.....	656
Union 67 (10)	110	553	230	433	225	438	235	428	440	223	.....	.....	.....	.....	.....	.....	560	103	663

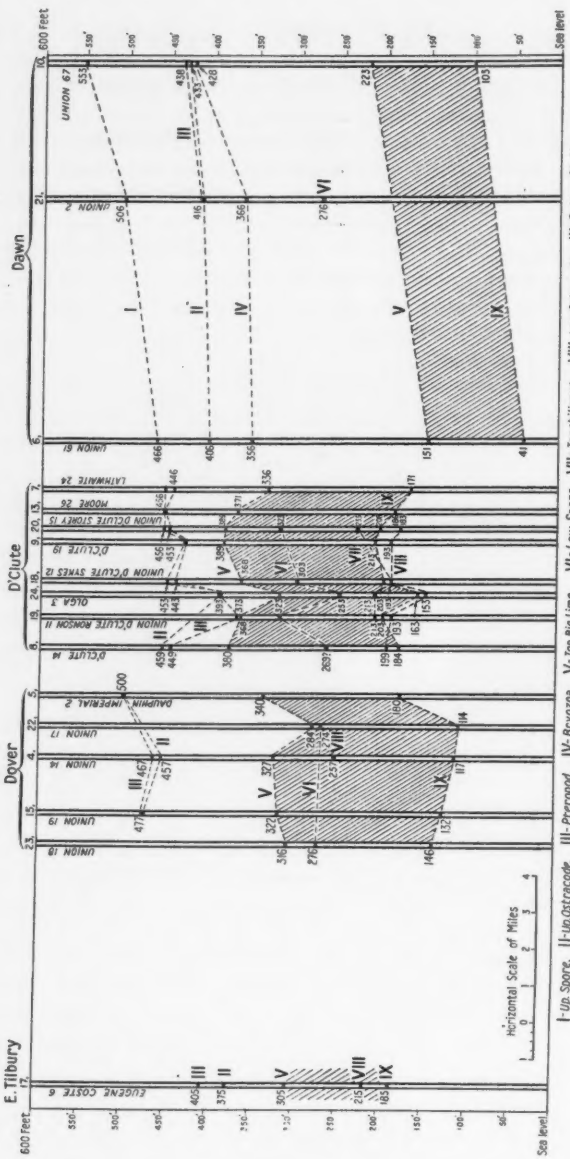

FIGURE 3.—*Graphs of fossil zones and Big Lime*

the D'Clute field where they have been traced through a thickness of 60 feet. They bear a striking resemblance to the so-called spores of the Huron shale. Occasionally the globular form is preserved, but usually they are much flattened, and the detail of structure is gone. The form is here referred to *Protosalvinia bilobita* (Dawson, 1886).

TROCHILISCUS ZONE

Peculiar little subspherical bodies, a millimeter in height with coarse spiral markings, characterize this horizon near the base of the Onondaga formation. Their vertical range is limited to about 30 feet but, unfortunately, they have been recognized in only four wells in the D'Clute field.

These fossils are herein referred to the genus *Trochiliscus* (Peck, 1934). They are thought to represent the fruiting bodies of a group of primitive aquatic plants—the Trochiliscaceae—common throughout the Devonian. The fossils are popularly referred to as "Chara Seeds" on account of their possible relationship to the modern *Charaphyta*.

LOWER OSTRACODE ZONE

This is one of the best-defined horizons studied. It is characterized by a new species of ostracode resembling the genus *Aparachites*. The form is sparingly developed but extraordinarily constant in its appearance throughout the lowest 60 feet of the Onondaga. Except in the Dawn, specimens of this ostracode have been identified from each of the fields under discussion. In the D'Clute field it is best represented, having been identified there in six of the eight wells studied.

TABULAR ARRANGEMENT OF FOSSIL AND PHYSICAL HORIZONS

Table 1 shows the position in the wells of both the fossil zones and the Big Lime. The position is expressed both in terms of depth in the wells and of elevation above sea level. In each case, unless otherwise stated, the figures refer to the tops of the zones. From this information the accompanying graphs (Fig. 3), showing the continuity of the fossil zones, have been prepared.

CONCLUSIONS

As a result of a study of samples from gas and oil wells from certain well-known fields in Lambton and Kent counties in southwestern Ontario seven horizons, based upon microfossils, have been located. The establishment of these horizons has afforded a means of checking the validity of the physical horizon—the Big Lime—commonly used by the well drillers to indicate deeper structures.

It is obvious that a physical horizon such as the Big Lime is more easily identified in the field than a microfossil horizon. It must be admitted,

however, that the consistent relationships of a number of fossil horizons is a more valid indication of the stratigraphic sequence. It has been shown by means of such fossil evidence that the top of the Big Lime is not uniformly developed in the various fields and, therefore, is not a reliable marker. The bottom of the Big Lime, however, bears a more consistent relationship to the fossil zones. It has been suggested, therefore, that the bottom of this physical unit rather than the top should be used as an horizon of reference.

Since the Big Lime even in the narrow limits of this region has been found to vary in thickness and lithological character, it is well realized that its use as a marker cannot be extended, with safety, to districts far removed from this area. It has been demonstrated, however, that within this section of Ontario there can be found a definite relationship between what might be termed valid fossil horizons and a physical marker easily recognizable in the field.

In any corresponding section of the Middle Devonian it is almost certain that a similar sequence of microfossils could be found which could be correlated with a physical marker recognizable in that field, even as in southwestern Ontario the bottom of the Big Lime may be correlated with the microfossil zones of this area.

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PRE-CAMBRIAN AND PALEOZOIC ALGAE

BY CARROLL LANE FENTON AND MILDRED ADAMS FENTON

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ABSTRACT

Calcareous algae, some of which are replaced by chert, are abundant in several pre-Cambrian, Cambrian, and Mississippian formations of the Northwest Territories of Canada and the Rocky Mountains of Wyoming and Montana, and in Ordovician formations of the upper Mississippi Valley. Several form-genera and form-species persist over considerable areas in spite of variations in the sediments which contain them. Some form-species produced massive biostromes, while others made limestone "mottlings" in dolomites or produced irregular layers. Fluctuations within form-species may be correlated with evidence of environmental variation.

INTRODUCTION AND ACKNOWLEDGMENTS

This paper assembles studies of fossil calcareous algae and associated sediments in the Rocky Mountains of Wyoming, the Northwest Territories of Canada, and southeastern Minnesota. Most of the collections and field studies were made by the writers during 1936 and 1937, thanks to a grant from the Geological Society of America. The Department of Geology, Princeton University, supplied Cambrian specimens and secured the pre-Cambrian algae collected by Dr. Joliffe of the Bureau of Geology and Topography, Canada.

Type specimens of *Collenia septentrionalis* sp. nov. are in the National Museum of Canada and the geological Museum of Princeton University; original types of *Cryptozoon minnesotense* Winchell and *C. minnesotense libertatis* Winchell are in the geological museum of the University of Minnesota. Hypotypes of that species, as well as holotypes and paratypes of all new species described in this paper except *C. septentrionalis* have been deposited in the Carnegie Museum, Pittsburgh. Metatypes and other authentic material have been sent to the British Museum (Natural History), the Royal Ontario Museum, the Botanical Museum of Harvard University, geological Museum of Princeton University, and other institutions.

The writers' thanks are due the Geological Society of America and Drs. R. M. Field, B. F. Howell, and Erling Dorf of Princeton University. Dr. S. H. Knight materially aided field work in the Medicine Bow Mountains, while Mr. Howard Stagner, of the National Park Service, assisted in the Teton Range. Dr. Fred Joliffe generously provided field notes and photographs as well as specimens, and Mr. M. L. Austin and Mrs. Henry Smith guided the writers to exposures of Mississippian algae in the Big Horn Mountains. Dr. Christina Lochman provided a manuscript section based upon her detailed work in the Beartooth Butte regions. Dr. Julius Pia has examined sections of algae, specially the tubular *Aulophycus*.

PRE-CAMBRIAN ALGAE FROM THE NORTHWEST TERRITORIES, CANADA

DESCRIPTION AND OCCURRENCE

Collenia septentrionalis sp. nov.

(Plate 1, figures 1, 2)

DESCRIPTION: Elongate domes or elongate-columnar colonies whose length generally is more than twice their width. They are irregular in rate and direction of growth; some of them bifurcate. They consist of flexuous laminae which are convex upward

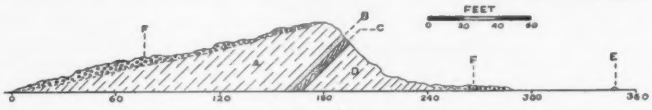

FIGURE 1.—*Cross section of algal island in Marion Lake, N thwest Territories*

A, algal dolomite locally containing siliceous lenses showing no algae. B, dolomitic sandstone. C, cross-bedded sandstone. D, algal dolomite. E, most easterly exposure of algal dolomite. F, drift and boulders. (Field sketch by F. Joliffe, Bureau of Geology and Topography, Canada.)

and which number 10 to 18 in a thickness of 5 millimeters. Within some colonies, the laminae form mammillae 15 to 22 millimeters in diameter; in others they are almost uniformly curved. Weathered upper surfaces of the biostromes are wrinkled, domed or mammillate. Colonies are closely packed or confluent; where spaces intervene, they are filled with sandy dolomite.

REMARKS: This species probably includes the algae described by Rutherford (1929), from limestones of Great Slave Lake. It resembles *Collenia kona* Twenhofel (1919, p. 346), of the Lower Huronian, but its colonies are more distinct and less regularly vertical in growth; available specimens do not indicate the basal union into nearly horizontal laminae that is shown in Twenhofel's Figure 1. They also are much smaller than the large masses illustrated in his Figure 2. In its manner of growth, this species resembles *C. columnaris* Fenton and Fenton (1937, Pl. 9) of the Belt series, though its columns are less regular in attitude and size, and unite into compound colonies. *C. columnaris* also is found in sandy dolomites; sand which fills spaces between colonies of *C. septentrionalis* is subangular or rounded; its grains range from 0.2 to 1.0 millimeters in diameter.

HOLOTYPE: 24011 Princeton University; PARATYPES: 24012 Princeton University and specimen in the National Museum of Canada.

OCCURRENCE: Dr. Fred Joliffe, who collected the types, reports that they occur in early or middle pre-Cambrian dolomites associated with dolomitic sandstone, with probabilities favoring early pre-Cambrian (Archeozoic) age. The algae occur on a small island in Marion Lake, Northwest Territories; it lies near longitude 116° 15′ and latitude 63°, being shown just west of the letter "R" on Map 331A of the Geological Survey of Canada (South Sheet, Rae-Great Bear Lake Area, District of Mackenzie, 1936). Similar biostromes, on the eastern arm of Great Slave Lake, are reported by Dr. C. H. Stockwell.

Algae or Colloidal Bodies

(Plate 1, figures 3, 4)

REMARKS: Drs. Joliffe and Kidd report that cherts on Mystery Island, Echo Bay, Great Slave Lake, contain concentrically laminated balls and irregularly laminated

expansions whose character is shown by the illustrations. Some resemble small algal colonies; others suggest distorted masses of colloidal silica. Specimens are not available for sectioning.

OCCURRENCE: Echo Bay Group (Proterozoic). These bodies lie in cherts which are cut by pitchblende veins whose lead-uranium ratios indicate an age of at least 1,200,000,000 years and place the structures in the late Keewatin.

PRE-CAMBRIAN ALGAE FROM THE MEDICINE BOW MOUNTAINS, WYOMING

DESCRIPTION AND OCCURRENCE

Hadrophycus, gen. nov.

hadros, mighty; *phykos*, sea plant

GENOHOLOTYPE: *Hadrophycus immanis* sp. nov.

DESCRIPTION: Large dome-shaped or expanded algae which consist of irregularly flexuous or crumpled laminae and thick, approximately vertical pillars which seem to be preserved only in chert deposits. The most distinct pillars give the colonies a spongy appearance. Algae of this genus form massive biostromes in which colonies are distinct but closely crowded, or stratified biostromes in which the algae comprise flexuous and crumpled laminar sheets which covered and formed the sea floor. The least crumpled layers are barely distinguishable from inorganic sediments.

Hadrophycus immanis sp. nov.

(Plate 2, figures 1-4; Plate 3, figures 1, 2)

DESCRIPTION: Domes, biscuit-shaped masses and laminar colonies. Typically, they consist of laminar heads in which dolomite and chert layers alternate: each layer contains 6 to 14 laminae whose thickness ranges from 0.2 to 6.5 millimeters. Some dolomite layers contain irregular, carbonaceous laminae. In many colonies the laminae bear low mammillae. Very large, highly silicified masses are porous and show no laminae, but preserve irregular, imbricating columns 1 to 6 millimeters in diameter. Colonies range from 10 to 300 centimeters (4 inches to 10 feet) in height and 50 to 500 centimeters (20 inches to 16.6 feet) in transverse diameter. Some are elongate, the length being almost twice the width and more than twice the thickness.

Dome- or biscuit-shaped masses of *H. immanis* seem to be ecads developed in biostromes during relatively rapid sedimentation and disturbed water. Slow sedimentation and quiet water seem to have conditioned the laminar ecads (Pl. 2, fig. 3), which spread upon the bottom without demarcation of colonies and with varying degrees of bending or crumpling. Such sheet-like growth was halted by either periodic or local accumulation of sediment, producing both uniform and irregular banding in the colonies.

REMARKS: Blackwelder (1926, p. 637-639) first called attention to the presence of large algal masses in dolomitic marbles of the pre-Cambrian Nash formation in the Medicine Bow Mountains. He figured one colony but did not name or formally describe it, stating only that in Walcott's opinion it was "probably referable to the genus *Collenia*." These algae also were familiar to Dr. S. H. Knight, who directed the writers to them in 1936.

OCCURRENCE: *H. immanis* is scattered through the upper 1700 feet of the Nash formation in the Medicine Bow Mountains of Wyoming. The general nature of its occurrence is shown by the following section (Sec. 16, T 17 N, R 79 W, Medicine Bow Sheet):

	Feet	Inches
44. Marble, pink to buff, banded, in beds 6 to 15 inches thick; much carbonaceous material near base. Algae doubtful	45	
43. Marble, white, pink and buff, thickly bedded. Algae doubtful	75	
42. Marble, gray, banded buff and pink; micaceous	12	
41. Schist, gray, with some beds of pink to buff marble 6 to 18 inches thick and one thick quartzite band. No algae seen	282	
40. Marble, pink, thickly bedded	3–4	
39. Schist, gray	9	
38. Marble, gray to buff, laminated; pink; jasper bands	7–9	
37. Covered	2	
36. Schist, gray	6	
35. Marble, pink, laminated. No distinct algae, though flexuous jasper laminae may be algal deposits. Largely covered	24	
34. Schist and slate, gray, banded	21	6
33. Marble, pinkish buff; algae are expanded masses or low domes	10	9
32. Schist and slate, gray, finely laminated	2	6
31. Marble, grayish brown, containing jasper nodules	2	8
30. Schist and slate, gray, finely laminated	11	
29. Marble, gray, with chert laminae; algal colonies are large, depressed domes as much as 45 inches in diameter and 20 inches high	2	2
28. Marble, gray, with many crumpled jasper laminae which probably are algal	3	6
27. Marble, gray; contains flattened concentric algal masses which lie at varied angles	1	2
26. Marble, white, cream or pink; lenses, laminae and nodules of jasper. No distinct algae	3	
25. Schist and slate, gray, finely laminated	18	
24. Marble, gray, weathers brown; basal 2 feet contain irregular laminae of jasper and dolomitic marble which may be algal	8	
23. Schist and slate, dark gray with black laminae; some buff, dolomitic marble	31	
22. Marble, dolomitic, creamy buff, finely laminated. Algae small, depressed domes	2	6
21. Slate, black, and gray schist	3	9
20. Dolomite, gray, weathers buff; one bed	1	4
19. Schist and dolomitic marble, dark gray; lenticular black slate at base	8	
18. Algae in expanded domes with undulant to coarsely mammillate upper surfaces; 22 to 45 inches in transverse diameter	4	6
17. Marble, dolomitic, crystalline, pink; irregularly laminated; many quartz veins	12	
16. Schist, gray, weathers brown	4	
15. Marble, dolomitic, crystalline, pink; irregularly laminated	3	9
14. Schist and dolomitic marble, gray	8	4
13. Marble, dolomitic, dark gray, in one bed	1	3

	Feet	Inches
12. Algae in small heads and expanded, laminar masses which form a continuous bed; their laminae consist of dolomite and jasper	2	4
11. Marble, dolomitic, dark gray, thickly bedded; much quartz in veins and thin laminae	8	6
10. Marble, dolomitic, gray to brown, thickly bedded; contains sandy and cherty laminae. Masses suggesting algae present	3	
9. Schist, gray, weathers brown; thickly bedded	2–3	
8. Marble, dolomitic, white to gray, thickly bedded	4	
7. Marble, dolomitic, sandy, gray, thinly bedded, containing crinkly laminae of chert and jasper	3	
6. Dolomitic schist, gray	1	5
5. Marble, dolomitic, gray; jasper nodules and layers in the basal 3 to 6 inches. No algae in the lowest 18 to 24 inches; above this they form laminae and small nodules	4	8
4. Covered. Talus includes silicified algae and blocks of gray dolomitic marble which weathers buff-gray. Elsewhere, this member consists of brown, gray and pink marble interbedded with waxy jasper in gray and olive-yellow bands	72–75	
3. Marble, dolomitic, gray, weathers gray; contains layers of brown-weathering chert. Crowded by very large dome-shaped to columnar colonies of algae separated by lenses of sediment	52–55	
2. Marble, dolomitic, buff to brown, and pink cherts, enclosing columnar colonies of algae 4 to 8 feet in diameter	33	
1. Argillite, impure, gray to blue-gray. Apparently the uppermost beds of No. 1 in Blackwelder's Telephone Lakes section	20	

Numbers 2 and 3 are variable; their sediments form bands and lenses among algae. At one point, No. 3 includes:

	Feet	Inches
f. Algae, laminar, and dome-shaped, not columnar	14	
e. Marble, dolomitic, gray, filling spaces between algae; contains the colony of Blackwelder's Figure 8	15	6
d. Algae, contorted domes and layers, grading into columnar masses	7	
c. Marble, dolomitic, banded with jasper; contains biscuit-shaped algae with contorted layers	2–4	
b. Dolomite and marble, laminated; shaly in some places	4	
a. Algae, dome-shaped to columnar, 8 to 16.6 feet in diameter	10–12	
	52–55	

Numbers 12 to 14 of Blackwelder's section comprise the middle zone of *Hadrophycus immanis*. Their 410 feet of marble, slate and schistose beds are exposed near the road to Libby Lake, and are divisible into six members:

	Feet	Inches
6. Marble, buff, pink and gray, interbedded with gray slate and schist. Near the top, thinly-bedded marbles contain calcareous algae which grew in isolated masses 6 to 12 inches in diameter	165	

	Feet	Inches
5. Marble and dolomite, gray, banded; many layers are crowded with dome-shaped and laminar algae, most of which are continuous basally; domes are 30 to 56 inches in diameter	65	
4. Marble, dolomitic, in one resistent bed		6
3. Like No. 5, except that algae form irregularly laminated expansions	16	6
2. Marble, dolomitic, gray, interbedded with schist and crystalline chert. Algae scattered through many beds. 30 feet below the top is a 3-foot biostrome formed by continuous, irregularly crumpled algal laminae	113	
1. Marble, gray, interbedded with schist and chert layers; finely laminated near base, some laminae numbering 18 to 32 per inch. Algae are laminar masses and domes which reach 40 inches in thickness	50	
	410	

The upper algal bed is exposed near Towner Lake and near the highway on the hill west of Telephone Creek. It consists of gray, dolomitic marble, with laminae of gray to brown jasper and bands of slate. Algal beds are light gray marbles, which weather olive buff; they contain indistinct algal masses 10 to 24 inches in diameter, which show the characters of *Hadrophycus*.

HABITAT: Rocks containing *Hadrophycus immanis* are metamorphosed limestones and dolomites, some of which were shaly. They are associated with banded slates and chlorite schists which may have been true shales. Both slates and impure marbles contain laminae whose thickness is compatible with seasonal banding. Some laminae are carbonaceous, indicating rhythmic organic deposits of presumably seasonal origin. Mud breccias do not appear in algal beds or others of the Nash formation, but in No. 27 of the section south of the Libby Lake road, algal colonies lie at varied angles, as if moved about by currents or waves.

By analogy and contrast with the Belt series (Fenton and Fenton, 1937, p. 1929-1935), the writers conclude that *Hadrophycus* inhabited clear, shallow waters in a sea subject to seasonal fluctuations in light but probably not in temperature. During periods of mud accumulation, which may represent shallowing and change to lagoons (Blackwelder, 1926, p. 656), the algae obviously retreated to other habitats, returning as water deepened and chemical deposition was resumed. There is no trace of shallowing of water by evaporation, or seasonal floods from arid lands. On the contrary, Blackwelder suggests that the finely laminated phyllites which overlie the Nash formation indicate moist climate, mild temperature, and an abundant terrestrial vegetation of lichens, mosses and similar plants. He also regards the dolomites, in which most of the algae lie, as indicators of tropical conditions. To the writers, they suggest greater warmth than do muds of the phyllites, but no great contrast with periods in which shales and dolomitic schists were deposited.

CAMBRIAN ALGAE OF THE TETON RANGE, WYOMING

STRATIGRAPHIC RELATIONSHIPS

Cambrian strata are widely distributed on the western slope of the Teton Range, both in and beyond Grand Teton National Park. Within the Park, they are most accessible at the head of Death Canyon, in

benches and cliffs below Housetop Mountain. General stratigraphic features of these Cambrian strata have been discussed by Blackwelder (1918, p. 418) and Miller (1936, p. 127-129), and Blackwelder (1915) described massive calcareous algae in one persistent zone. Since neither of those authors gave special attention to algae, however, the section at the head of Death Canyon is repeated with mention of algae and sedimentary structures which indicate their habitats. Thicknesses are generalized, since there is considerable variation within this typical exposure.

Stratigraphic names used in this section require some explanation. The Snowy Range formation is determined by the presence of *Collenia magna* sp. nov. as well as by stratigraphic position and lithology; it apparently corresponds to the lower half of the Snowy Range on Beartooth Butte. The shale called, for convenience, the *Billingsella* zone probably is a remnant of a barren shale 80 feet thick which lies below the *Collenia magna* zone on Beartooth Butte.

The Pilgrim formation corresponds to the Gallatin or Lower Gallatin of authors; it apparently corresponds to the Pilgrim of Deiss (1936, p. 1319, 1333-1335), and the Lower Gallatin of Dorf (1934, p. 724), and is the Gallatin of Miller (1936, p. 124). Because of the presence of *Aulophycus callosus* sp. nov. in both, it is correlated with the *Crepicephalus* zone of the Maurice formation on Beartooth Butte, as the Cambrian section there is now divided by Lochman and Dorf.

Members 5 to 12 comprise the Gros Ventre formation of Blackwelder (1918, p. 418-419). Since Lochman and Dorf assign apparent equivalents of these strata to the Upper Cambrian Maurice and the Middle Cambrian Park and Meagher formations, the term Gros Ventre is not employed.

Numbers 5 to 10 form the Death Canyon member of Miller (1936, p. 119-120). Correlation of No. 10 with the *Tetonophycus blackwelderii* zone of Beartooth Butte places it in the Upper Cambrian. The writers found neither animal remains nor *Girvanella* in Nos. 5 to 9, but *Aulophycus repens* sp. nov. does closely resemble an *Aulophycus* that is abundant in the upper part of the Meagher formation on Beartooth Butte. On this basis, the writers tentatively draw the Middle-Upper Cambrian boundary at the top of the *Aulophycus repens* zone, whose upper surface seems to be eroded. With this restriction, Death Canyon is retained as a facies designation for Nos. 5 to 9, which seemingly correspond to the Meagher and Park formations of Beartooth Butte. Mud breccias in No. 6 indicate more disturbed waters than those of the Beartooth Butte area, with conditions which both removed sedi-

ment and prevented development of the Meagher formation in its typical facies.

Section at head of Death Canyon,
Grand Teton National Park

UPPER ORDOVICIAN

Bighorn formation

	Feet
25. Dolomite, mottled buff, in massive beds from 1 to 12 feet thick; crowded with irregular bodies interpreted as partly diagenized calcareous red (coralline) algae. Estimated thickness.....	280
24. Dolomite, mottled gray and buff, massively bedded; lower portion lacks recognizable coralline algal structures.....	8
	288

—Disconformity—

UPPER CAMBRIAN

Snowy Range formation

Collenia magna zone

23. Dolomite, gray to buff-white; weathers gray to light brown. Beds are massive; they form two biostromes containing crowded colonies of *Collenia magna* sp. nov.....	45–50

—Disconformity—

Billingsella zone

22. Limestone, blue-gray, fine-grained to shaly, containing *Billingsella* and masses resembling *Aulophycus*. A lenticular deposit which fills depressions in the eroded surface of the Pilgrim formation. Elsewhere, it has been removed by erosion.....	0–3
	45–53

—Disconformity—

Pilgrim formation

Brachiopod zone

21. Dolomite, gray to buff, thinly and evenly bedded. Contains *Irvingella, Eoorthis* (?) and *Linnarsonella*.....	10
20. Dolomite, mottled buff and brownish, gritty, with finely laminated beds. Many channels and pits. Brachiopods abundant in some beds.....	10

Aulophycus callosus zone

19. Limestone, mottled buff- and blue-gray, shaly and thinly bedded. Crowded with tabular and expanded colonies of *A. callosus* sp. nov. Trilobite fragments abundant. A lenticular deposit.	0–5

Aulophycus prolificus zone

18. Dolomite, gray; weathers deep buff; beds from 2 to 8 inches thick. *A. prolificus* sp. nov. common; other fossils rare.....	14–20
17. Dolomite, brownish; weathers buff; beds from 0.5 to 2 inches thick. They are crowded with *A. prolificus* sp. nov.....	6

Collenia spissa zone

	Feet
16. Limestone, gray; some strata mottled with olive- or buff-brown; bedding massive. The member forms one or two massive biostromes of *C. spissa* sp. nov. Lenses and fillings between algae are oölites, pisolites or mud breccias; some contain *A. prolificus* sp. nov. Estimated thickness	90
15. Dolomite, mottled gray and buff, in beds from 4 to 6 inches thick. No algae	2
14. Limestone; one massive bed of *C. spissa* sp. nov	1.5–3
13. Limestone, gray, interbedded with buff dolomite; both thinly bedded. Contains at least one small algal reef; limestones probably are algal. *A. prolificus* sp. nov. common	1.5–3.5
	135–149.5

Lower Maurice formation (equivalents)

Mud Breccia zone

12. Limestone, gray to olive, thinly bedded, interbedded with olive-gray, calcareous shale. Most of the limestone is flat-pebble or edgewise mud breccia, pebbles ranging from 4 to 50 millimeters in width	18–20

Rivularites zone

11. Shale greenish-gray, thinly bedded; some layers are sandy but others are micaceous. Sandy layers contain *Rivularites* and annelid burrows	200

Tetonophycus blackwelderii zone

10. Limestone, black and dark gray, interbedded and mottled with dolomite which weathers rusty brown. It is crowded with colonies of *T. blackwelderii* sp. nov. which are 2 to 5 feet in transverse diameter and 1 to 2.5 feet high. The matrix weathers to chips and nodules; weathering of algae is discussed in the description of the species. The basal 8 to 12 inches consist of mottled limestone and dolomite, probably algae	5–7
	225–227

—Disconformity?—

MIDDLE CAMBRIAN

Death Canyon facies (Park and Meagher equivalents)

Aulophycus repens zone

9. Limestone, buff to gray, and buff-weathering dolomite in beds 0.5 to 3 inches thick. *A. repens* sp. nov. is common throughout, but is most abundant in the upper 20 inches	10±
8. Limestone, gray to blackish, fine-grained, regularly but thinly bedded; interbedded and mottled with buff-weathering dolomite; thin shale partings	140
7. Shale, greenish gray, and thinly bedded gray limestone	15±
6. Limestone, gray, shaly, thinly-bedded, containing strata of edgewise mud breccia	110
5. Limestone, light gray, thinly bedded, weathers buff to brown	6–8
	280–285

Wolsey formation

	Feet
4. Shale, greenish to purplish gray, thinly laminated, containing thin beds or lenses of sandy shale, shaly mud breccia and argillaceous gray sandstone	102
	102

Flathead formation

3. Sandstone, fine- to medium-grained, red to brown, interbedded with olive to gray-green, arenaceous shale	35
2. Quartzite, white gray and grayish pink, in massive beds	85
1. Sandstone, coarse, arkosic; red, purple and gray. Cross-laminated in some strata; others are regularly bedded	55
	175

—Unconformity—

DESCRIPTION AND OCCURRENCE

Tetonophycus gen. nov.

Teton (name of mountains); *phykos,* sea plant

GENOHOLOTYPE: *Tetonophycus blackwelderii* sp. nov.

DESCRIPTION: Calcareous algae forming massive, biscuit-shaped colonies which consist of closely compacted or confluent columns and subconical mammillae. In the one known species, each conical mass consists of a basal concavo-convex dome formed by radiating columns divided by irregular spaces, and an outer zone composed of irregularly laminated mammillae whose outer surface is channeled and pitted. This division seems to be the most significant character.

Tetonophycus blackwelderii sp. nov.

(Plate 4, figures 1, 2)

DESCRIPTION: Colonies large, the majority being from 2.5 to 5 feet in transverse diameter and from 1 to 2.5 feet in height. The basal zone is from one-third to two-thirds the total height; it consists of intermittently confluent columns whose laminae are crumpled and depressed-convex. Spaces between them are filled by non-laminated dolomite which weathers brick-red. In many masses, the algal laminae are lost, but the columns and interspaces remain, producing a mottled, "spongy" texture. This basal zone ends abruptly, in an irregularly convex surface which bears no discernible sedimentary parting. Above it lies the mammillate zone, which consists of flexuous, columnar or pear-shaped masses that are distinct but contiguous, are confluent, or are separated by irregular, sediment-filled spaces. Varied groups of these unite into abrupt domes or subconical elevations which rise 4 to 10 inches above the intervening pits and furrows. Their surfaces are botryoidal, divided by still smaller irregular mammillae, which represent the constituent lumps and columns. Both mammillae and depressions are crossed by irregular, imbricating channels 0.5 to 1.2 millimeters wide which are filled with sediment and so do not represent recent solution, though they may be confused with fractures channeled by solution. Except that they do not radiate, the true channels resemble those on the surface of *Syringostroma* and similar stromatoporoids.

REMARKS: Blackwelder (1915, p. 648-649) described and illustrated the structure of *Tetonophycus blackwelderii,* though his figure indicated too great uniformity

in the "heads" of the superficial mammillate zone, and merely suggested columns in the basal zone. He also called attention to the light color of matrix between the dark algal material, suggesting that dolomitization of the colonies progressed

FIGURE 2.—*Tetonophycus blackwelderii* sp. nov.

(A) natural section of the upper part of the basal zone showing confluent columns, layers, and fillings; (B) natural section of basal and upper zones showing differences in structure and loss of layers in the basal zone. Dolomite fillings are stippled. (x 0.15.)

from the outside inward. It may have done so, but in all specimens examined by the writers, the basal zone is more highly dolomitized than the upper, mammillate zone. Of the two, the former has the less distinct laminar structure and contains the larger amount of iron oxide.

The abrupt change in growth-form of *T. blackwelderii* lacks explanation. It did not take place simultaneously, for it is found in colonies which lie at different levels.

It does appear at approximately uniform heights above the bases of all colonies which the writers examined, suggesting that growth carried the algal colonies into a water stratum whose physical conditions differed significantly from those of the stratum immediately above the sea bottom. In convex colonies, however, the central part of the growing surface must have reached such a second stratum first while the periphery reached it last, and the change in growth-form should appear along a plane corresponding to the base of the second stratum. Actually, the change appears above a convex boundary which once was the colony's upper surface, and whose height above the bottom varied as much as 15 or 20 centimeters within a single algal mass.

Despite these difficulties in interpretation, the change in growth-form seems to be a result of external conditions. On Beartooth Butte, where *T. blackwelderii* lies in a matrix of limy, semi-plastic shale with small lenses of coarse material and mud breccia, the growth-form is dominantly that of the basal zone in colonies of the Tetons. Only colonies which reached presumably disturbed water developed the mammillate zone.

Occurrence: *Tetonophycus blackwelderii* zone in ledges below cliffs of Housetop Mountain and along the Skyline trail in Grand Teton National Park. Blackwelder found the species 1.9 miles N. 64° W. of B. M. 10,685, Grand Teton Quadrangle, on the divide between the forks of Leigh Creek. It also occurs at Beartooth Butte; Dr. Lochman reports it from other localities in southern Montana.

As the Death Canyon section shows, *Tetonophycus blackwelderii* at its type locality occupies a single diffuse biostrome above basal mottled layers whose thickness varies. In Beartooth Butte, east of Yellowstone National Park, the *Tetonophycus blackwelderii* zone contains three major strata. At the base is a dense, gray algal limestone 3 to 3.6 feet thick; above it lie 0.8 to 2 feet of shaly algal limestone which grades laterally into edgewise mud breccia. The third stratum is a biostrome in which algal masses reach 3 feet in thickness and 6 feet in width. The total thickness is 10 to 14 feet.

The *Tetonophycus* biostrome at the head of Death Canyon is underlain by thinly bedded, mottled limestones and dolomites in which calcareous masses are 1 to 4 centimeters thick and 4 to 8 centimeters wide. They seem to be exaggerations of the "mottled" growth-form which is best shown by *Aulophycus prolificus* sp. nov., and may be of algal origin. Though these calcareous masses are relatively small in layers 8 to 12 inches below the *Tetonophycus* biostrome, they were not seen to intergrade with typical *Aulophycus repens,* from which they probably are separated by a disconformity.

Collenia spissa sp. nov.

(Plate 6, figure 2; Plate 7, figure 3)

Description: Erect, columnar to pear-shaped colonies which consist of layers and laminae which are moderately to abruptly convex. Laminae number 6 to 12 in 5 millimeters; they form resistant layers 3.5 to 25 millimeters thick, divided by weak zones. Some columns are irregularly pitted by cavities which suggest the burrows of sponges; these cavities are filled with buff-weathering dolomite. Most colonies are packed closely together; others are distinct and are separated by sediment, as is shown in Figure 2. In some cases this sediment is crowded with balls of crystalline calcite; in others, it consists of dolomite and irregular expansions of *Aulophycus* or similar algae, with which *C. spissa* may be interbedded. In one case (Fig. 3), columnar colonies of *C. spissa* form a small reef, or bioherm, from which laminar expansions extend, forming layers of gray calcite among dolomite.

REMARKS: *Collenia spissa* forms massive biostromes; the reef-building habit seems exceptional. Within a single stratum, colonies of algae fuse and divide, or shift from low masses to columns. These changes are shown by Figure 2 of Plate 6.

In several strata near the type locality, distinct colonies of *C. spissa* give way to lenticular layers of laminated gray limestone between other layers of buff-weathering

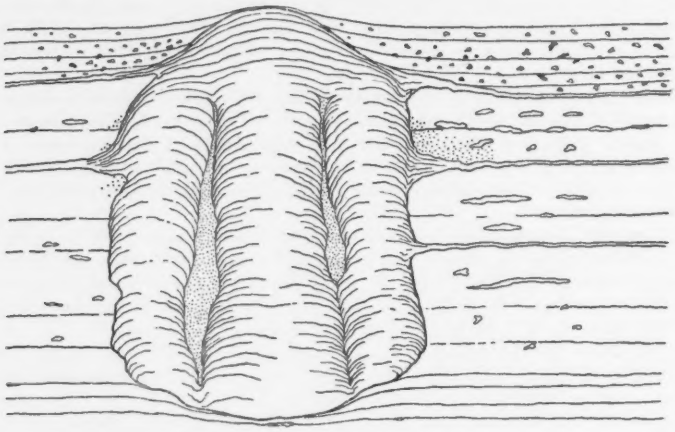

FIGURE 3.—*Collenia spissa* sp. nov.

Cross section of a reef or bioherm of this species, 35 inches high; its colonies fuse at top and bottom, and send out expansions which form limestone layers among layers of dolomite. Near them are lenticular masses assigned to this species. Thinly bedded dolomite above the bioherm contains *Aulophycus prolificus* sp. nov. Stippling indicates coarse-grained dolomite which contains a few small, rounded pebbles of limestone.

dolomite. Rough layers closely resemble modern calcareous deposits whose origin and algae have been described by Tilden (1897). Changes from flat-lying laminated layers to irregular, nodular deposits containing indistinct laminae are correlated with variations in algal growth and distribution, determined by presence or absence of currents. Inorganic laminae in associated limestones and dolomites suggest that smooth algal layers developed in very quiet waters, while nodular layers were produced during periods of slight but recurrent disturbance. A different assemblage of species may be the basis of morphologic distinction, so that layers of different character (Pl. 7, fig. 3) may be biologically distinct. Since specimens show no microstructure, however, these variants as well as distinct colonies are regarded as ecads or growth-forms of a single species.

OCCURRENCE: *Collenia spissa* zone of the Cambrian (Pilgrim); head of Death Canyon and elsewhere in the Teton Range.

HABITAT: Like several species of *Collenia* in the Belt series, *C. spissa* seems to have inhabited areas of shallow, relatively clear water. At first, such habitats offered hard mud bottoms with little shifting sediment. With development of biostromes, the algae provided their own hard bottom. Locally and periodically, the waters were sufficiently disturbed to deposit mud breccias and interrupt algal growth, but such disturbances were neither so frequently repeated nor so violent as those

that produced breccias in the Goathaunt member of the Beltian Siyeh formation (Fenton and Fenton, 1937, p. 1907). Sedimentation was slow, at least in contrast to that which produced the *Aulophycus prolificus* zone.

Collenia magna sp. nov.
(Plate 5, figures 1, 2)

DESCRIPTION: Columnar colonies which are elongate-oval in transverse section, and abruptly dome-shaped on their upper surfaces. The holotype, an exceptionally

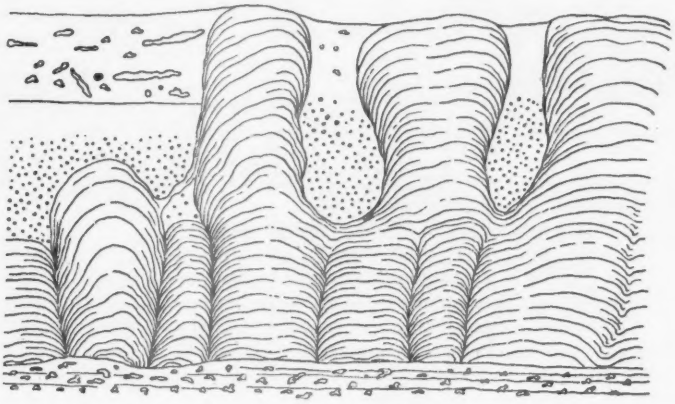

FIGURE 4.—*Collenia spissa* sp. nov.

A biostrome of this species resting on thinly bedded dolomite containing *Aulophycus prolificus* sp. nov. The algal colonies fuse and divide; sediments between them contain balls of calcite crystals. At the upper left are lenticular algae which grade into *Aulophycus*-like forms. Much reduced.

small colony, is 5.5 inches in greatest diameter and 10.3 inches high. Typical colonies are 2 to 6.5 feet in diameter and from 4 to 12 feet high. Laminae are indistinct; they number 4 to 7 in 5 millimeters. Basal laminae are widely expanded, gently convex plates; succeeding laminae extend beyond them and recurve marginally, producing the appearance of wrinkles as is shown in Figure 1 of Plate 5.

REMARKS: This species is characterized by its shape and the great size of typical colonies, which crowd closely together in massive biostromes. The holotype is selected for reference only; illustrations show typical field specimens, which are abundant in fallen blocks of dolomite and also may be seen in cliffs of Housetop Mountain.

OCCURRENCE: Snowy Range formation; foot of Housetop Mountain, at the head of Death Canyon (type locality), and elsewhere in Grand Teton National Park, Wyoming. *C. magna* also forms biostromes along Grove Creek, near Red Lodge, Montana; on Beartooth Butte, and along the east fork of Mill Creek, north of Yellowstone National Park.

Aulophycus gen. nov.

aulos, tube; *phykos,* sea plant

GENOHOLOTYPE: *Aulophycus repens* sp. nov.

DESCRIPTION: Calcareous tubes and grooved, terete "stems" which are simple, branched or irregularly reticulate; they are horizontal or vertical in position and spread into palmate, nodular or laminar expansions in which tubes are few.

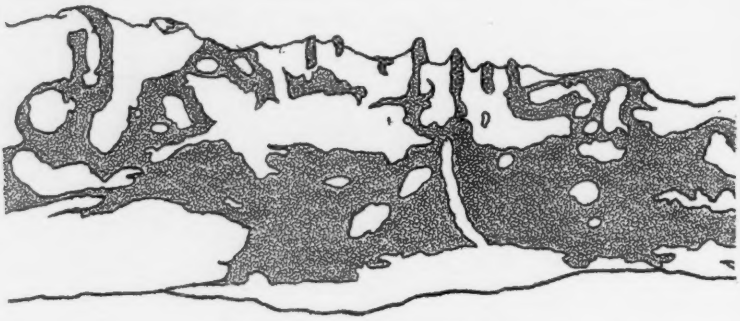

FIGURE 5.—*Aulophycus repens* sp. nov.
Vertical section through the holotype, showing laminar, fused masses and tubes. (x 1.)

REMARKS: In Pilgrim strata, *Aulophycus* is closely associated with *Collenia spissa* sp. nov., appearing in spaces between colonies of that alga, and in beds between biostromes. Some layers of *Aulophycus* lie between those of *C. spissa* and spread laterally, giving a false impression that the two are identical. Distinct tubes of *Aulophycus* resemble those of *Palaeophycus* Hall (1847, p. 7), of the Ordovician, while grooved bodies resemble the piece shown in Figure 1 d of Hall's Plate 22. In all cases, however, *Aulophycus* tubes and "stems" show expansions, which have not been found in *Palaeophycus.*

Layers, nodules and palmate expansions of *Aulophycus* are massive or contain laminae which number 12 to 18 in 5 millimeters. Like expansions of *Collenia spissa,* they show that many calcareous layers and "mottlings" are of algal origin even though they show no definitely organic structure.

HABITATS: Relationships and contrasts of habitat in *Aulophycus* may be most concisely shown by this summary for the known form-species.

A. repens, the genotype, is found most abundantly in thinly bedded, gray dolomite which contains much clay; it is less abundant in interbedded limestones. Both dolomite and limestones weather buff, the former becoming dark. Bedding is regular except for masses and tubes of the algae, which rise above the beds or fill depressions in underlying beds. Mud breccia, sand and cross laminae are lacking. The abundance of algae suggests adequate aeration of shallows, without disturbance of bottom muds, which seem to have been hard.

An undescribed *Aulophycus* in the upper Meagher formation of Beartooth Butte resembles *A. repens* in size but is very closely matted and has such thick walls that it forms limestone though the matrix is clay.

A. prolificus is found in buff-weathering dolomites with traces of cross lamination. Distribution of the algae suggests that sedimentation was rapid and was accompanied by frequent but moderate disturbance of the bottom. There is some evidence that the initiation of rapid deposition killed *Collenia spissa* and allowed *A. prolificus* to replace it.

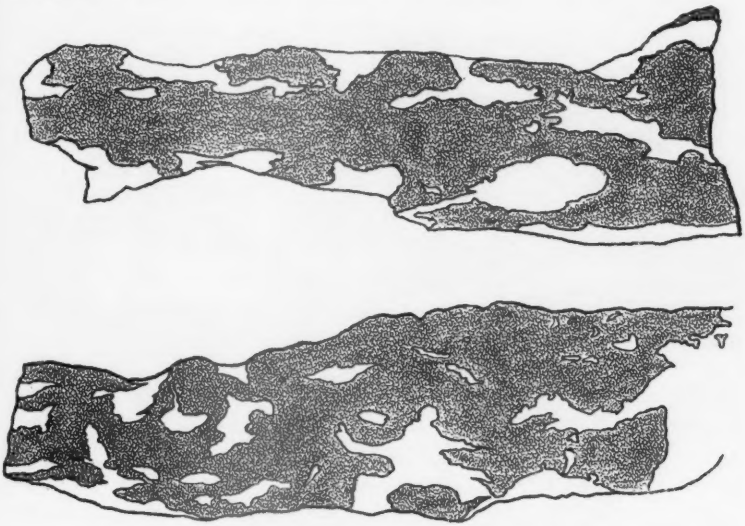

FIGURE 6.—*Aulophycus prolificus* sp. nov.
Two vertical sections through the holotype; most of the filled tubes and rods are cut longitudinally. (x 1.)

A. parvus seems to have occupied bottoms much like those on which *A. prolificus* thrived though they probably had less rapid sedimentation and somewhat greater disturbance by water movement.

A. callosus formed limestone in a matrix of gray to buff clay or lime mud; algal tubes and expansions grade laterally and basally into limestone beds. Water evidently was more clear and quiet than that in which other species thrived. There is no direct indication of depth. This form-species' preference for limy bottoms also is shown on Beartooth Butte.

Aulophycus repens sp. nov.
(Plate 7, figures 1, 2)

DESCRIPTION: Prostrate to vertical tubes whose outside diameter ranges from 3 to 11.8 millimeters; their walls are 0.6 to 6 millimeters thick. Apertures are constricted or expanded; tubes branch and fuse in irregularly reticulate patterns. Basally, the tubes unite in irregular, nodular or "spongy" layers, most of whose tubes are horizontal; those above this zone are dominantly vertical or oblique.

REMARKS: This is the most uniform in character of the three species now forming the genus. Its colonies do not divide into distinct nodular mottlings; even the

thickest basal expansions show distinct tubes which may be correlated with those rising above the massive portions. The matrix is buff-weathering, non-laminar dolomite containing much clay; it suggests that *A. repens* grew on bottoms which were at least moderately disturbed by waves or currents, though in water more quiet than that in which *Tetonophycus* grew.

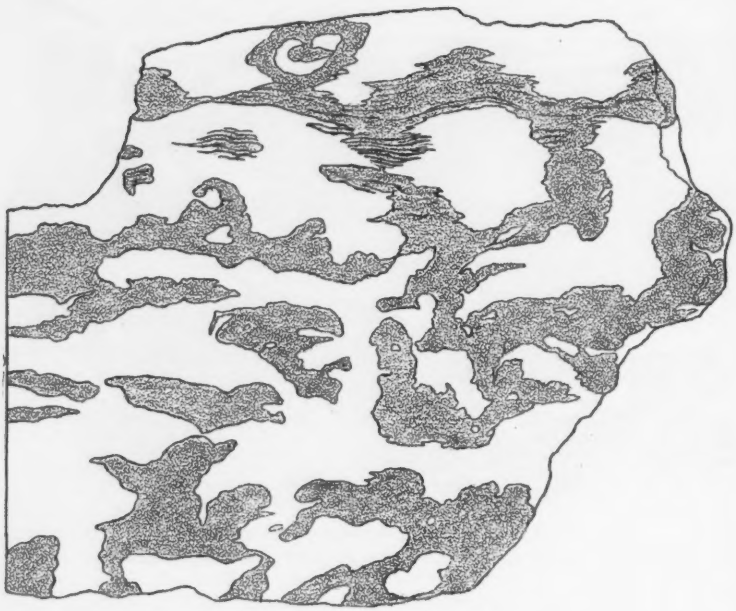

FIGURE 7.—*Aulophycus prolificus* sp. nov.
Natural section showing irregular and laminated growth forms of this species. (x 1.)

OCCURRENCE: Abundant in the *Aulophycus repens* zone of the Death Canyon facies; head of Death Canyon (type locality) and elsewhere in the Teton Range. It also seems to occur in the upper part of Number 8 of the Death Canyon section.

Aulophycus prolificus sp. nov.
(Plate 6, figure 1; Plate 7, figures 3, 4)

DESCRIPTION: Terete, branching, prostrate tubes which are from 4 to 11 millimeters wide and from 3 to 7.5 millimeters high, with walls from 1 to 4 millimeters thick. Tubes spread laterally into irregularly laminar sheets; others form irregularly nodular lenses, or even more irregular vesicular masses. A few lenses show distinct, flexuous laminae, but others are massive. Laminar algae are covered by laminated dolomites; massive ones lie in non-laminated sediments.

REMARKS: The lenticular and nodular ecads of this form-species are the commonest types of *Aulophycus* above the Lower Maurice equivalents; they are abundant among

biostromes of *Collenia spissa* as well as in the *Aulophycus prolificus* zone, where they are the dominant algal fossils. The lenticular type closely resembles, and perhaps intergrades with, the laminar ecad of the *C. spissa* complex.

OCCURRENCE: *Aulophycus prolificus* and *Collenia spissa* zones of the Pilgrim formation; head of Death Canyon (type locality) and elsewhere in the Teton Range.

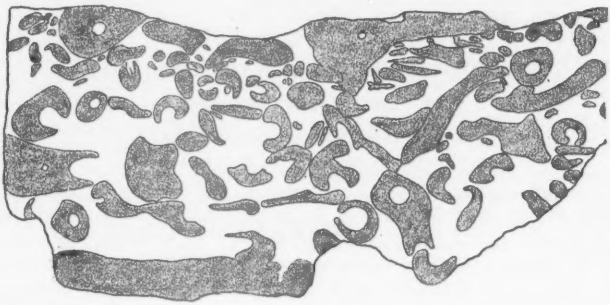

FIGURE 8.—*Aulophycus callosus* sp. nov.
Vertical section through the holotype, showing tubes, channeled rods and laminar expansions. (x 1.)

Aulophycus callosus sp. nov.
(Plate 8, figures 1, 2)

DESCRIPTION: Typical colonies of this form-species consist of prostrate, branching tubes or channeled rods underlain by irregular, massive or laminated layers. The layers form the basal portions; some are structureless, while others show indistinct tubes surrounded by tabular calcareous deposits. Above them lies a network of tubes and channeled rods which appear as broad, irregular U's in transverse section. Both tubes and rods expand into layers which are flexuous or oblique. Diameters of tubes range from 5 to 18 millimeters.

REMARKS: This species differs from *A. prolificus* in having tubes whose cavities are large in proportion to the total diameter. It also forms close networks, and its layers are more extensive than those of *A. prolificus*. Though the distinction between growth-forms probably is environmental, its basis has not been determined.

OCCURRENCE: *Aulophycus callosus* zone of the Pilgrim formation; head of Death Canyon (type locality) and elsewhere in the Teton Range.

Aulophycus parvus sp. nov.
(Plate 7, figure 5; Plate 8, figure 3)

DESCRIPTION: Typical colonies consist of basal layers and lenses formed by tubes fused and surrounded by structureless or indistinctly laminated deposits of limestone and are overlain by branched networks of tubes which are 1 to 4 millimeters in outside diameter. Inside diameters range from 0.3 to 1.5 millimeters. The species, therefore, is the smallest known member of the genus.

REMARKS: Except for laminae, the massive growth-form of this species resembles current-piled masses of tubes or colloidal calcite. Their upper surfaces bear pits

1.5 to 5 millimeters in diameter and 0.3 to 1 millimeter in depth. They are filled with buff-weathering, earthy dolomite. In one paratype, tubes lie in dolomite that contains irregular depressions 2 to 7 millimeters deep, which are filled with limestone. The broken condition of the tubes suggests that they grew in disturbed water, which eroded the older masses below them.

OCCURRENCE: Thinly bedded, buff-weathering mottled dolomites near the top of the *Collenia spissa* zone (Pilgrim formation). Head of Death Canyon (type locality) and elsewhere in the Teton Range.

ORDOVICIAN CRYPTOZOA OF MINNESOTA

DESCRIPTION AND OCCURRENCE

Cryptozoon minnesotense Winchell

(Plate 9, figure 1; Plate 10, figure 1)

Cryptozoon Minnesotense WINCHELL, Geol. Nat. Hist. Surv. Minn. 14th Ann. Rep. (1886) p. 313, pl. 1, figs. 1-2, pl. 2, fig. 3; CHANEY, Minn. Acad. Nat. Sci., Bull. 3 (1892) p. 280; DAWSON, Can. Rec. Sci., vol. 7 (1896) p. 206.

ORIGINAL DESCRIPTION: "The specimens from Cannon Falls show . . . six or eight laminae in a quarter of an inch, as visible to the eye. In a thin section . . . the laminae are as numerous as ten to fourteen in a quarter of an inch (Pl. II, fig. 3). Furthermore the Cannon Falls specimens are . . . shaped like the fossil from the Trenton which is well known as *Chaetetes petropolitanus*, but attain an immense size. [16 inches in diameter, 8 inches high] . . . They also are seen to overlap each other and to be of various shapes when crowded in the rock. . . . The under surfaces of perfect specimens are concentrically striated or ridged." (Winchell, p. 314).

REMARKS: Winchell does not mention or figure undulations or mammillae upon the upper surface of the algal colonies, though the latter are conspicuous on the upper surface of the specimen illustrated in his Plate 1. Since they most readily distinguish *Cryptozoon minnesotense* from other Cryptozoa in the Ordovician and Ozarkian of the upper Mississippi Valley the specimen of that plate is made lectoholotype and one other mentioned by Winchell is reduced to the status of lectoparatype. From the lectoholotype and new hypotypes, this revised description is offered:

REVISED DESCRIPTION: Nodular, hemispherical or expanded concavo-convex colonies whose upper surfaces are undulant to finely or coarsely mammillate. Laminae conform to the upper surface; in most specimens, they alternate in color and thickness, dark laminae being thinner than light ones. They number 12 to 18 in 5 millimeters and are 0.1 to 2 millimeters thick. Two growth forms are recognizable.

Form A.

Depressed-hemispherical, nodular or subspheroidal colonies whose upper surfaces bear round mammillae which are 7 to 30 millimeters in diameter and 1.5 to 6 millimeters high. In most specimens, the mammillae become strong after the diameter exceeds 10 centimeters; in large colonies, they are grouped upon large, rounded lobes or divisions. Laminae are grouped into layers 3 to 8 millimeters thick. Diameters of colonies reach 100 centimeters; thicknesses reach 45 centimeters.

This is the typical form of the species and the one to which Winchell's description applies. It is the only one found at Cannon Falls, where it occurs in a 12-inch

bed of earthy, coarse-grained dolomite. This form seems to be an ecad developed on bottoms of moderately rapid deposition on which particles were not larger than clay grains.

Form B

Depressed subhemispherical to concavo-convex colonies which resemble young stages of Form A. Their surfaces bear low, rounded elevations but few or no distinct mammillae. Laminae are flexuous in vertical section. Diameters reach 115 centimeters and thicknesses 65 to 70 centimeters. In small to large masses, this variant often is found in pure dolomites and limestone; it is an ecad that developed in relatively clear water with a minimum of clay and other clastic sediment. It is the principal biostrome builder of the species.

LECTOHOLOTYPE: 5685; LECTOPARATYPE: 6487 Geological Museum, University of Minnesota.

OCCURRENCE: *Cryptozoon minnesotense* occurs in the Shakopee formation at Cannon City, west of Point Douglas, at Preston, west of Lanesboro and many other localities in Minnesota and adjoining parts of Wisconsin and Iowa. The original type locality is Cannon Falls. Hypotypes collected at Cannon Falls and at the locality on U. S. Highway 52 near the Root River.

The general section in which this species occurs is best shown on U. S. Highway 16, west of Lanesboro, Minnesota. It is (Stauffer, 1935, p. 99, 436):

	Feet
St. Peter formation. Sandstone, yellow, massive	90–150
Shakopee formation. Dolomite and limestone, buff to gray, finely crystalline, in thin to thick beds	50.9
New Richmond formation. Sandstone, dolomitic, yellow to yellow-brown, soft	38
Oneota formation. Dolomite, gray to buff, massive	120+

In this section, the lower 12 to 14 feet of the Shakopee form the *Cryptozoon minnesotense* zone. With 14 to 15.3 feet of overlying strata, this zone is best exposed in a cut on U. S. Highway 52, approximately 0.5 mile north of Root River and 6.8 miles north of the junction with U. S. Highway 16, at Fountain. The measured section is:

	Inches
11. Dolomite, fine-grained, buff, in beds 4 to 8 inches thick	96
10. Limestone, buff, dolomitic, with some green-gray layers; thin minor but thick major beds	60–75
9. Limestone, buff, dolomitic, crystalline, oölitic, in two beds	12
8. Limestone, buff, shaly, yielding locally to irregularly bedded gray-buff limestone. Contains fairly distinct algal colonies (*C. minnesotense libertatis* Winchell), separated by thin partings of limestone	15–25
7. Limestone, buff, shaly, in thin, flexuous beds which cover algal colonies like those of No. 8	12–22
6. Shale, blue-gray, fine-grained thinly laminated, weathers to soft, clay. It contains small nodules and lenses of sand, which lie in depressions between the algae of No. 5	0.5–3
5. Dolomite, buff, with some oölites. A closely packed biostrome of *C. minnesotense* form B in colonies which reach 36 inches in width and 12 inches in thickness	30–45

	Inches
4. Dolomite, gray-buff with gray mottlings, porous to finely crystalline. A single biostrome of *C. minnesotense libertatis* in colonies 4 to 40 inches wide. The upper surface contains some mud breccia	60
3. Dolomite, buff-gray with blue-gray mottlings. Closely packed with small colonies of *C. minnesotense libertatis*	12–15
2. Sandstone, greenish gray to buff; lenticular, discontinuous	0.5–4
1. Limestone, buff, dolomitic; lenses of mud breccia whose pebbles have sublithographic texture	4

Talus conceals 1.5 to 2 feet of strata which separate No. 1 from soft, brownish-yellow New Richmond sandstones.

Near the Chicago Great Western Railway and south of the bridge east of U. S. Highway 52, in Cannon Falls, the basal Shakopee contains *C. minnesotense* of form A. The section is:

Shakopee formation	Inches
9. Dolomite, buff, thinly and irregularly bedded. Algae few	18
8. *Cryptozoon minnesotense* form A, in closely packed colonies of varied sizes, separated by earthy buff dolomite	12
7. Dolomite, buff, with "fucoidal" cavities; 3 irregular layers	11
6. Sandstone, brown, coarse, compact	3
5. Sandstone, white to buff, soft	3.5
4. Dolomite, buff, in 2 beds; laminae of the lower bed are undulant	5
3. Shale, whitish gray, thinly laminated; contains many thin laminae of sand. Grades upward into No. 4	5–6
2. Dolomite, thin-bedded, gray-buff	9–10
New Richmond formation	
1. Sandstone, brown, soft, thinly bedded; upper surface undulant, bosses rising as much as 20 inches. Average thickness (base hidden)	36

On U. S. Highways 10 and 61, approximately 0.5 mile west of Point Douglas, Shakopee dolomites contain a single band of *Cryptozoon minnesotense* form B in colonies 20 to 40 inches wide. They overlie dolomitic oölites. Some dolomite laminae seem to be continuous with major laminae within the colonies. The strata form a gentle arch overlying a massive dolomite with convex, undulant upper surface. It may be a low reef or bioherm of algae. Flexuous layers, some of which are mud cracked, lie near the base of the Shakopee.

Cryptozoon minnesotense libertatis Winchell

(Plate 9, figure 2)

Cryptozoon Minnesotense var. *libertatis* Winchell, Geol. Nat. Hist. Surv. Minn. 14th Ann. Rep. (1886), p. 314, pl. 2, fig. 4.

ORIGINAL DESCRIPTION: "The specimens obtained at Northfield . . . are subcylindrical with a conical upward apex. They are from one to three inches long, the length depending apparently on the circumstances that attend their removal from the enclosing rock, and from one to two inches in diameter. They appear, outwardly, like a succession of cups, or thimbles, piled on each other, the lower end of each covering the upper, closed end of the one below it. But the lower edge of each cup is ragged and capriciously fractured, due to the weathering out of the specimen

from the enclosing rock, for it is probable that the specimens would not be discovered except for the distinctness of the cup-shaped lamination which is made conspicuous by exposure to the weather. It is evident that they are not always

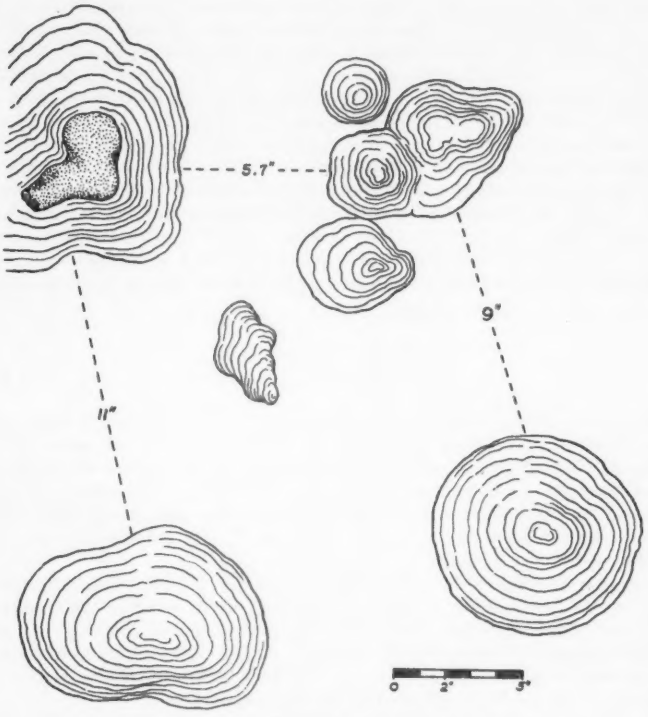

FIGURE 9.—*Cryptozoon confluens* sp. nov.

Under surface of a slab of Oneota dolomite showing colonies of *Cryptozoon confluens* in place. The colony at the upper left grew upon an irregular mass of oölite (stippled). Near railway level at second bridge north of Point Douglas, Minnesota, in the ravine of an intermittent tributary of the St. Croix River.

cylindrical, nor sub-cylindrical, since the impressions of the apices of several, remaining on the under surface of a small slab of rock, are somewhat elongated, though the most of these are concave, and shaped like the conical tops of the most of the detached specimens. The frayed edges of the laminae vary in frequency and in thickness. Generally two or three occupy the space of a quarter of an inch, but the intimate structure shows . . . from six to ten laminae in a quarter of an inch."

REMARKS: Though Winchell regards his holotype as a complete colony, his mention of "frayed" edges and his figure indicate that it is a single mammilla of a large, compound colony which has been broken into sections. Since complete

colonies whose mammillae correspond to the type have been found, the following revised definition is offered:

REVISED DESCRIPTION: Expanded plano-convex or concavo-convex colonies which reach 100 centimeters in width and 15 centimeters in thickness. They consist of abruptly and irregularly convex or subconical mammillae which are 10 to 70 millimeters in diameter and are separated by abrupt, angular furrows which are 3 to 40 millimeters deep. In vertical section, the elevations show abruptly curved laminae which number 4 to 9 in 5 millimeters and unite in layers 4 to 6 millimeters thick. They are confluent from one mammilla to another, though fracturing divides them into sections which Winchell mistook for separate colonies.

This subspecies is found in light gray, dolomitic shales which contain small lenses and balls of sandstone; the colonies are overlain by similar deposits. Perhaps *C. m. libertatis* is an ecad of the *C. minnesotense* complex developed in habitats of clastic deposition, but its colonial shape and mammillae warrant retention of Winchell's name.

SYNTYPES: 2391 and 2563 Geological Museum, University of Minnesota.

OCCURRENCE: Shakopee at Northfield, near Lanesboro, and on U. S. Highway 52 near the Root River, Minnesota.

Cryptozoon confluens sp. nov.

(Plate 10, figure 2)

DESCRIPTION: Colonies depressed hemispherical, concavo-convex, or plano-convex with variable outline. Observed diameters range from 6 to 25 centimeters and thicknesses from 3 to 9 centimeters. Colonies consist of laminae 0.1 to 0.5 millimeters thick; they join in layers 2 to 4 millimeters thick. Mammillae and undulations are lacking. Some colonies are isolated; others are closely crowded; the majority are confluent in their outer portions. A few colonies surround oölitic nodules or flattened masses.

REMARKS: The writers have been unable to determine the relationships of this fossil to large, subspherical or hemispherical algae which occur in the Oneota near Burkhardt, Wisconsin. They lie in relatively pure dolomites and may be either a distinct subspecies or an ecad of *C. confluens*. As here defined, this species seems to form a reliable index fossil of the upper Oneota. It is more closely related to *C. proliferum* Hall than is either growth form of *C. minnesotense*.

OCCURRENCE: *Cryptozoon confluens* was found in dolomites approximately one mile north of Point Douglas, Minnesota, but the principal observed occurrence is in the quarry in Mankato, where this section was measured:

	Inches
New Richmond formation	
10. Sandstone, soft to hard, buff to dark brown. It is cross-laminated and ripple-marked, and contains flat pebbles of shaly dolomite. The basal 36 inches are softer than the strata above	84–96
Oneota formation	
9. Dolomite, buff, sandy, soft, mud-cracked	2–8
8. Dolomite, buff-gray, sandy or oölitic, with bands and lumps of oölitic sand. Forms the matrix of the uppermost algal bed	2–6
7. Sandstone, gray to buff-yellow, hard; matrix of the lower algal bed	4–8
6. Sandstone, gray, lenticular	0–1

	Inches
5. Sandstone, gray-buff, oölitic, contains quartz pebbles 4 to 14 millimeters long and dolomitic nodules	0.5–1
4. Dolomite, buff to brown, fine-grained, in two beds	3.5–5
3. Dolomite, deep buff, sandy; contains rounded quartz pebbles and dolomitic flat pebbles. Some lenses are mud breccia with sandy matrix	2–3
2. Dolomite, gray-buff, sandy; contains laminae of gray shale. At top, becomes nodular dolomite	4–5
1. Dolomite, buff, massively bedded; said to contain typical Oneota invertebrates. Extends to bottom of quarry.	

This section indicates that *C. confluens* inhabited bottoms of rapid, dominantly clastic sedimentation. Where sediments were finer, as in exposures north of Point Douglas, colonies reach their largest observed size and are least confluent. The types were collected from No. 8 of the section at Mankato.

MISSISSIPPIAN ALGAE FROM THE BIG HORN MOUNTAINS, WYOMING

DESCRIPTION AND OCCURRENCE

Codonophycus, gen. nov.

kodon, bell; *phykos*, sea-plant

GENOHOLOTYPE: *Codonophycus austinii* sp. nov.

DESCRIPTION: Bell-shaped, conical or columnar algal colonies which are connected with neighboring colonies by convex or undulant areas. In some cases, two or more connected columns rise from a single convex basal area. Structure consists of laminae and indistinct, horizontally radial pillars.

Codonophycus austinii sp. nov.

(Plate 11, figures 1-3)

DESCRIPTION: Colonies compound; they consist of convex laminae and of bell-shaped, columnar and conical elevations rising from the substratum or from convex basal laminae or layers. Laminae number 14 to 18 in 5 millimeters, the weak ones being very thin. New columns or cones rise by development of convex laminae over limited areas; these are covered by wider, less abruptly convex laminae which extend from column to column. Horizontally radial pillars which number 15 to 18 in 5 millimeters appear in weathered sections.

The compound colonies are of great extent; they form virtually continuous biostromes 20 to 40 inches thick whose surfaces are exposed over areas exceeding 0.5 square mile; they seem to have been continuous over much greater distances. The algal structures have been replaced by amorphous or grainy chert.

REMARKS: The specific name, *austinii*, honors Mr. M. L. Austin, of Shell, Wyoming, who discovered this alga; with his daughter, Mrs. Henry Smith, Mr. Austin guided the writers to the type exposure. Specimens exhibited by the late Mrs. Nellie Austin, at her museum in Shell, first brought the species to the writers' attention.

OCCURRENCE: *Codonophycus* biostromes occur in the Mississippian Madison formation at many exposures along the western slopes of the Big Horn Mountains, Wyoming (Darton, 1906). The type locality is cliffs above the canyon of Horse Creek, Bald Mountain Quadrangle. Eroded fragments of *C. austinii* are found in alluvium of the Big Horn Basin.

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EXPLANATION OF PLATES

PLATE 1

PRE-CAMBRIAN ALGAE, NORTHWEST TERRITORIES, CANADA

(1, 2) *Collenia septentrionalis* sp. nov.

(1) Weathered surface of the holotype. Early or middle pre-Cambrian dolomites. Marion Lake. (x 0.4.) (24011 Princeton University.)

(2) Weathered surface, showing several small colonies in almost vertical section. The match gives a scale.

(3, 4) Algal or colloidal bodies

(3) Two layers of laminar bodies which seem to be algae. Proterozoic, Echo Bay Group. Mystery Island. Great Slave Lake.

(4) Concentrically laminated balls which seem to be algae. Proterozoic, Echo Bay Group. Mystery Island, Great Slave Lake.

(Figures 2–4, from photographs by Dr. Fred Joliffe, are used by permission of the Director of the Bureau of Geology and Topography, Canada.)

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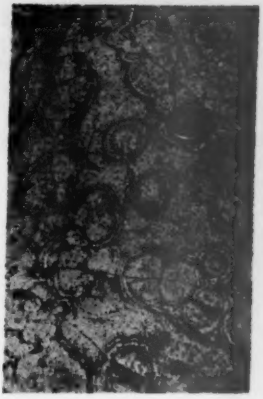

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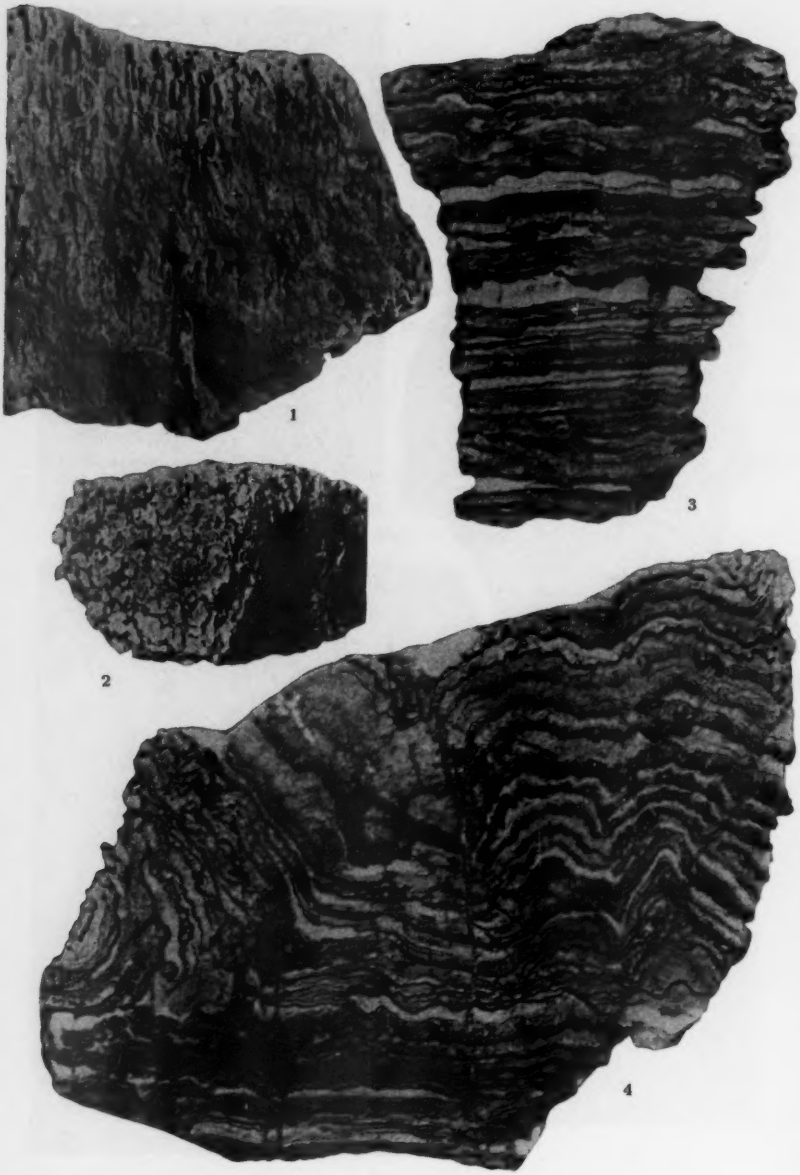
PRE-CAMBRIAN ALGAE, NORTHWEST TERRITORIES, CANADA



PRE-CAMBRIAN ALGAE, MEDICINE BOW QUADRANGLE, WYOMING

PLATE 2

PRE-CAMBRIAN ALGAE, MEDICINE BOW QUADRANGLE, WYOMING

Hadrophycus immanis sp. nov.

(1) Weathered fragment (paratype) showing vertical pillars. Nash formation, No. 3a. Libby Lake Road. (x 0.5.) (Carnegie Museum.)

(2) Weathered paratype, showing vertical pillars in transverse section. Nash formation, No. 3a. Libby Lake Road. (x 0.5.) (Carnegie Museum.)

(3) Weathered vertical section (paratype) of the laminar ecad of this species. Algal layers are chert; sedimentary layers, dolomite. Nash formation, No. 15 of Blackwelder's section. Near Towner Lake. (x 0.4.) (Carnegie Museum.)

(4) Weathered vertical section (holotype) through contorted dome grading into both columnar and crumpled laminar masses. Nash formation, No. 3d. Libby Lake Road. (x 0.4.) (Carnegie Museum.)

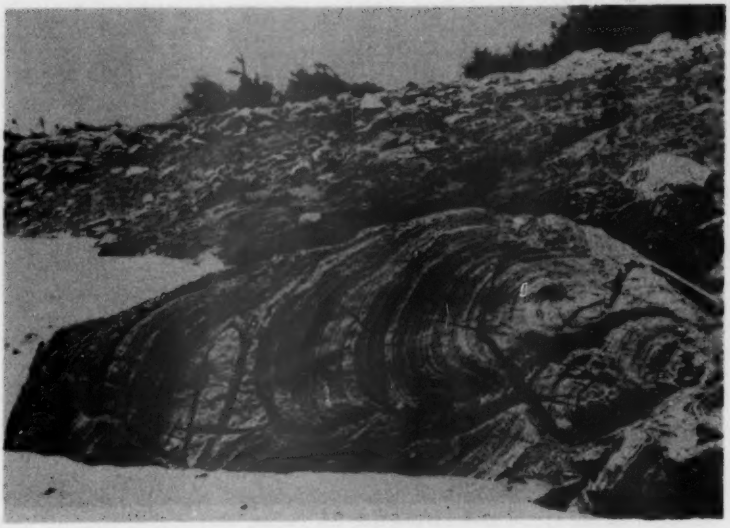
PLATE 3

PRE-CAMBRIAN ALGAE, MEDICINE BOW QUADRANGLE, WYOMING

Hadrophycus immanis sp. nov.

(1) Weathered, almost vertical section of a dome-shaped colony in a steeply dipping biostrome. Layers consist of chert and dolomite; height of the colony is about 7 feet. This is the colony of Blackwelder's figure 8 (1926). Nash formation, No. 3e. Near road to Class Lakes.

(2) Weathered section through a dome-shaped colony preserved in chert. It shows irregular pillars and thick layers. As this block lies, the pillars are horizontal instead of vertical, their original position. Nash formation, No. 3a. Libby Lake road.



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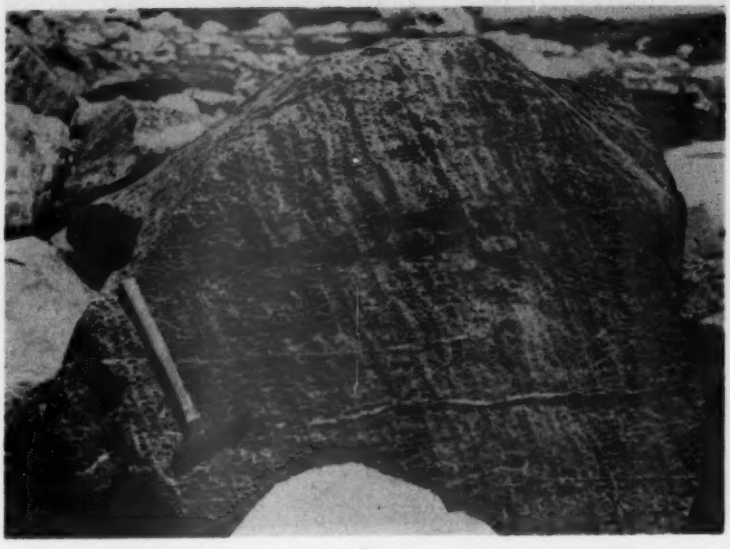

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PRE-CAMBRIAN ALGAE, MEDICINE BOW QUADRANGLE, WYOMING

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UPPER CAMBRIAN ALGAE, GRAND TETON NATIONAL PARK, WYOMING

PLATE 4

UPPER CAMBRIAN ALGAE, GRAND TETON NATIONAL PARK, WYOMING

Tetonophycus blackwelderii sp. nov.

(1) Weathered vertical section, showing the two zones of growth and the structure which produces the botryoidal surface and channels characteristic of this form-species. *Tetonophycus blackwelderii* zone. Head of Death Canyon.

(2) Surface of a colony, showing large, botryoidal mammillae of the upper zone. *Tetonophycus blackwelderii* zone. Head of Death Canyon.

PLATE 5

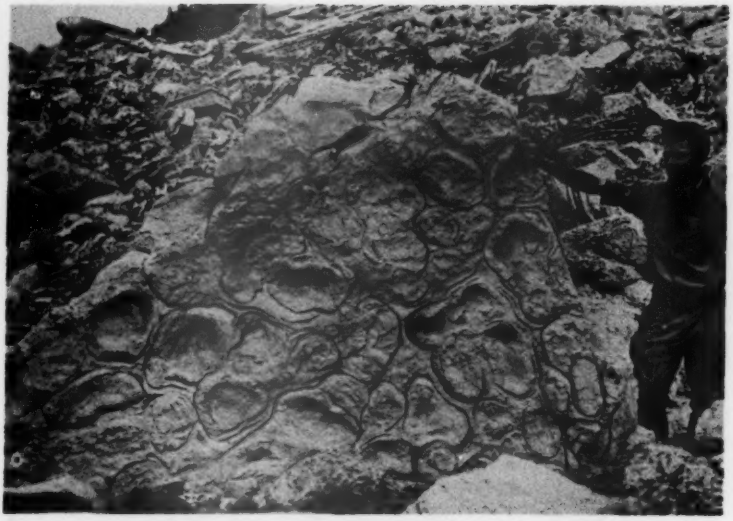
UPPER CAMBRIAN ALGAE, TETON MOUNTAINS, WYOMING

Collenia magna sp. nov.

(1) Under surface of a massive bed, showing the bases of typical colonies of this form-species. Snowy Range formation. Near head of Death Canyon, west of the boundary of Grand Teton National Park.

(2) Vertical section through the block shown in Figure 1. Man's hand rests upon the basal surface. These colonies are of average size; many found above them are wider and higher.

(Photographs by Margaret Haines.)



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UPPER CAMBRIAN ALGAE, TETON MOUNTAINS, WYOMING

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UPPER CAMBRIAN ALGAE, GRAND TETON NATIONAL PARK, WYOMING

PLATE 6

UPPER CAMBRIAN ALGAE, GRAND TETON NATIONAL PARK, WYOMING

(1) *Aulophycus prolificus* sp. nov.

Surface of the slab from which the holotype was taken; it shows both tubes and laminar expansions. Few tubes open vertically. Pilgrim formation, *Aulophycus prolificus* zone. Talus of Housetop Mountain, head of Death Canyon.

(2) *Collenia spissa* sp. nov.

Weathered vertical section, showing columns and laminar expansions. Pilgrim formation, *Collenia spissa* zone. Talus of Housetop Mountain, near head of Death Canyon.

PLATE 7

MIDDLE AND UPPER CAMBRIAN ALGAE, GRAND TETON NATIONAL PARK, WYOMING

(1, 2) *Aulophycus repens* sp. nov.

Upper surface of parts of the holotype, showing tubes and laminar expansions. Death Canyon facies, *Aulophycus repens* zone. Head of Death Canyon. (x 0.6.) (Carnegie Museum.)

(3) *Collenia spissa* and *Aulophycus prolificus* sp. nov.

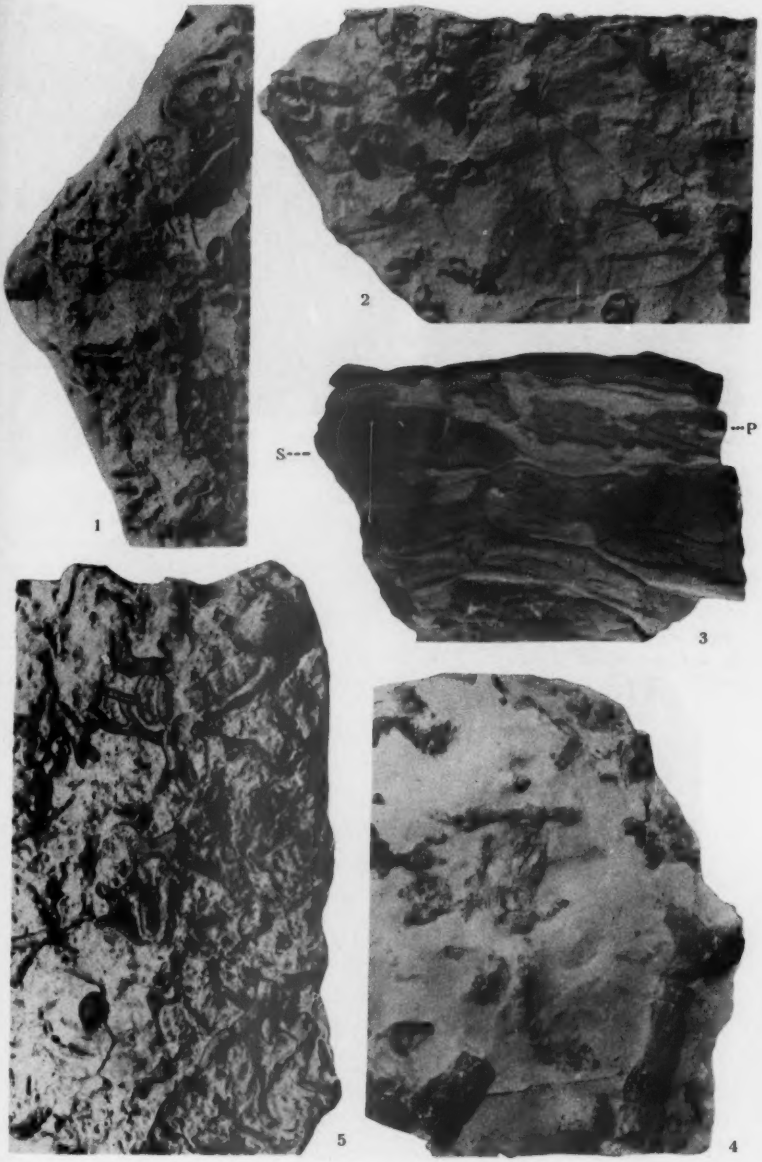
Weathered vertical section (paratype of *C. spissa* sp. nov.) containing the laminar ecad of that species, marked S, and the less compact laminar ecad of *Aulophycus prolificus* (P). Pilgrim formation, *Collenia spissa* zone. Housetop Mountain, at head of Death Canyon. (x 0.6.) (Carnegie Museum.)

(4) *Aulophycus prolificus* sp. nov.

Upper surface of part of the holotype. Pilgrim formation, *Aulophycus prolificus* zone. Talus of Housetop Mountain, head of Death Canyon. (x 0.6.) (Carnegie Museum.)

(5) *Aulophycus parvus* sp. nov.

Upper surface of the holotype, showing small, distinct tubes. Pilgrim formation, top of *Collenia spissa* zone. Housetop Mountain. Head of Death Canyon. (x 1.) (Carnegie Museum.)



MIDDLE AND UPPER CAMBRIAN ALGAE, GRAND TETON NATIONAL PARK, WYOMING

UPPER CAMBRIAN ALGAE, GRAND TETON NATIONAL PARK, WYOMING

PLATE 8

UPPER CAMBRIAN ALGAE, GRAND TETON NATIONAL PARK, WYOMING

(1, 2) *Aulophycus callosus* sp. nov.

(1) Upper surface of a paratype, showing an exceptionally large tube and nodular masses formed by union of tubes. Pilgrim formation, *Aulophycus callosus* zone. Housetop Mountain, head of Death Canyon. (x 0.6.) (Carnegie Museum.)

(2) Upper surface of the holotype, showing typical tubes and laminar expansions. Erosion of this specimen probably preceded fossilization. Pilgrim formation, *Aulophycus callosus* zone. Housetop Mountain, head of Death Canyon. (x 0.6.) (Carnegie Museum.)

(3) *Aulophycus parvus* sp. nov.

A weathered slab, showing tubes of this small species in mottled limestone and dolomite. The former may have been caught in algal jelly. Pilgrim formation, top of *Collenia spissa* zone. Housetop Mountain, head of Death Canyon. (x 0.6.) (Carnegie Museum.)

PLATE 9

ORDOVICIAN ALGAE, MINNESOTA

(1) *Cryptozoon minnesotense* Winchell, Form A

Upper surface of an exfoliated specimen whose mammillae and laminae are virtually identical with those of the holotype. Shakopee formation. Cannon Falls. (x 0.4.) (Carnegie Museum.)

(2) *Cryptozoon minnesotense libertatis* Winchell

Upper surface of a typical colony of this subspecies, which may actually be an ecad restricted to clastic habitats with disturbed water. Shakopee formation. U. S. Highway 52 near the Root River. (x 0.34.) (Carnegie Museum.)

1

2

ORDOVICIAN ALGAE, MINNESOTA

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2

ORDOVICIAN ALGAE, MINNESOTA

PLATE 10

ORDOVICIAN ALGAE, MINNESOTA

(1) *Cryptozoon minnesotense* Winchell, Form B

Upper surface of a colony which is virtually without mammillae, though the laminae are almost identical with those of the specimen shown in Plate 9, figure 1. Shakopee formation, in dolomite (No. 4) below the shale containing *Cryptozoon minnesotense libertatis*. U. S. Highway 52 near the Root River. (x 0.4.) (Carnegie Museum.)

(2) *Cryptozoon confluens* sp. nov.

Upper surface of a biostrome showing confluence of colonies, their small size and lack of mammillae. The holotype is one colony from this slab. Oneota formation, No. 8 of section. Quarry in Mankato.

PLATE 11

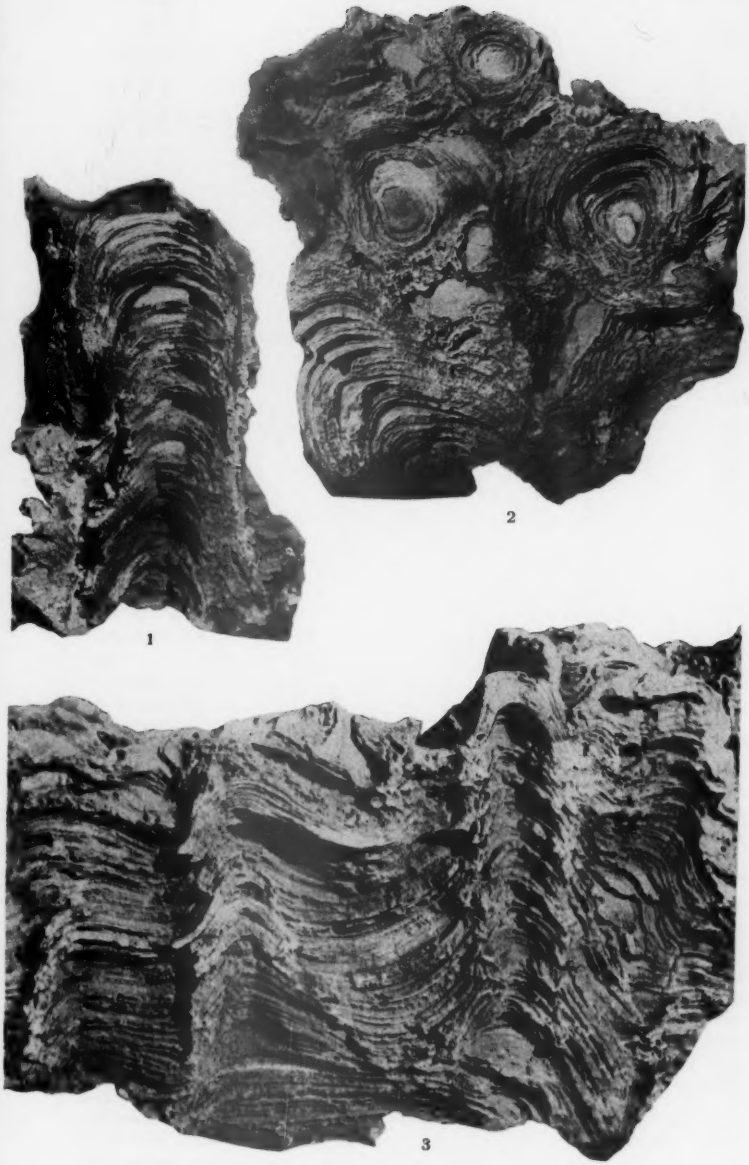
MISSISSIPPIAN ALGAE, BIG HORN MOUNTAINS, WYOMING

Codonophycus austinii sp. nov.

(1) Weathered vertical section (paratype), showing extreme development of a column. Madison formation. Near head of Horse Creek, Bald Mountain Quadrangle. (x 0.5.) (Carnegie Museum.)

(2) Weathered transverse section (paratype), with well developed columns and subconical mammillae. Madison formation. Near head of Horse Creek, Bald Mountain Quadrangle. (x 0.5.) (Carnegie Museum.)

(3) Weathered vertical section (holotype), which combines partly developed columns with concave interspaces. Madison formation. Near head of Horse Creek, Bald Mountain Quadrangle. (x 0.5.) (Carnegie Museum.)



MISSISSIPPIAN ALGAE, BIG HORN MOUNTAINS, WYOMING

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GEOLOGY OF THE MASCOMA QUADRANGLE, NEW HAMPSHIRE

BY CARLETON A. CHAPMAN

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ABSTRACT

Middle-grade and high-grade metamorphic rocks, derived from sediments and volcanics, which range from Middle Ordovician to Lower Devonian, comprise half the rocks in the Mascoma quadrangle. The Orfordville formation (probably Middle Ordovician) is a new formation. Biotite gneiss of the Oliverian and New Hampshire magma series comprise the rest of the rocks.

The outstanding structural features are domes of metamorphic rocks with cores of the Oliverian magma series. Evidence indicates these bodies are laccoliths. A primary foliation is believed to have developed in these igneous rocks parallel to the contacts and a schistosity produced parallel to the bedding in the roof rocks. Bedding, schistosity, and foliation are thus all parallel. Field and laboratory studies indicate that considerable microcline later replaced some of these igneous and metamorphic rocks, producing rocks with the composition of granite.

The Mt. Clough pluton of Bethlehem gneiss with a marked primary foliation paralleling its contacts is a later major feature. It was intruded probably in the late Devonian as a huge sheet essentially parallel to the regional structure. Field evidence indicates that it forced its way over two of the Oliverian domes while buried beneath several thousand feet of rock.

The area sheds considerable light on metamorphic problems. Chlorite (amesite) is stable in the presence of muscovite in the garnet zone. Kyanite forms in the lower part of the middle-grade zone. Disequilibrium rocks are believed to be common. Rotated porphyroblasts indicate a post-metamorphism deformation. Two distinct periods of metamorphism are evinced by the fact that the schistosity formed by laccolithic intrusion has in places been highly folded and a second schistosity superimposed.

INTRODUCTION

The Mascoma quadrangle, in west-central New Hampshire (Fig. 1), was mapped in 1927 by the topographic branch of the United States Geological Survey, on a scale of 1:62,500 and with a contour interval of 20 feet. The earliest studies in bedrock geology of the area include those of C. H. Hitchcock (1874, 1877, 1878, and 1909), but more recent studies have been made by J. W. Merritt (1921), J. W. Goldthwait (1925), and E. P. Kaiser (1938). In recent years considerable detailed work in

stratigraphy, structural geology, and petrology has been done in New Hampshire. Much of this was of considerable aid in the study of the present problem. Of particular importance is the work of M. P. Billings (1937) in the Littleton and Moosilauke quadrangles. Other important works will be found in the list at the end of this report.

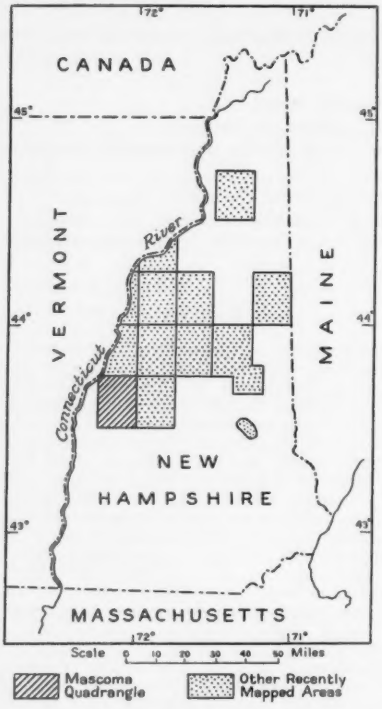

FIGURE 1.—*Index map*

Showing location of Mascoma quadrangle and other recently mapped areas.

METHOD OF WORK AND ACKNOWLEDGMENTS

The field work, which occupied 26 weeks, was carried on during the summers of 1935 and 1936. The 1932 edition of the United States Geological Survey topographical sheet was enlarged three times to a scale of 3 inches to 1 mile, and used as a base map in the field. All critical points were accurately located by means of pace-and-compass traversing or by an aneroid barometer, and all outcrops were recorded on maps. About five weeks were spent in making detailed pace-and-compass maps (scale of 800 feet

to the inch) in regions where the structure was relatively complex or where it was desired to trace contacts accurately.

Welcome coöperation was received from field parties working in adjoining areas; Doctors K. Fowler-Lunn and L. Kingsley (1937) in the

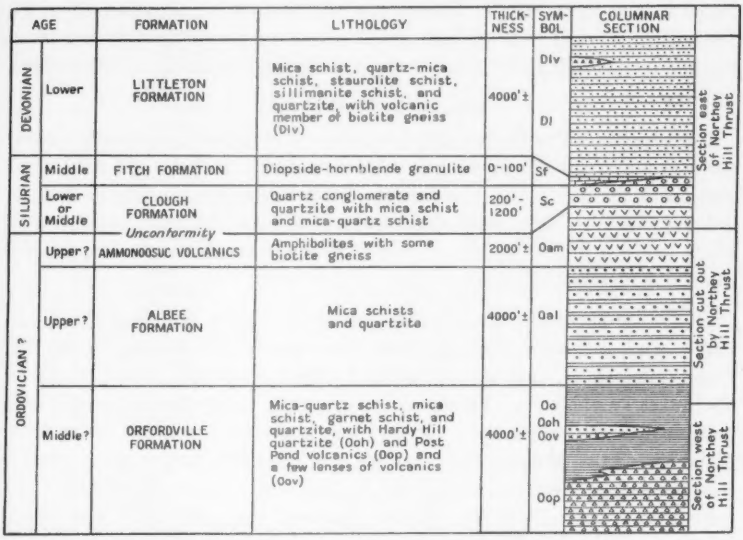

FIGURE 2.—*Columnar section of Mascoma quadrangle*

Cardigan quadrangle, Dr. J. B. Hadley (1938) in the Mt. Cube quadrangle, Dr. L. R. Page in the Rumney quadrangle (1937), and Mr. E. P. Kaiser (1938) in the Mascoma and Hanover quadrangles.

Sincere thanks are due Professor Marland Billings of Harvard University, for supervision of field and laboratory work and valuable assistance in the preparation of this paper, and to Professor E. S. Larsen, Jr., for the many helpful suggestions and criticisms. The writer was assisted in the field by Mr. B. F. Chapman, Mr. R. Vosburgh, and Mr. E. Breed, Jr., and for shorter periods by Dr. R. W. Chapman, Mr. W. E. Richmond, and Dr. J. B. Hadley. To these men the writer wishes to express his indebtedness. He also wishes to express his sincere thanks to Professor Charles Palache and the Department of Mineralogy and Petrography, Harvard University, for money obtained from the Holden Fund to finance field expenses and pay for thin sections; to Professor J. W. Goldthwait and Mr. F. E. Everett who obtained funds necessary for publishing the colored geological map; and to Dr. E. B. Dane, Jr., for the numerous photomicrographs used in this paper.

METAMORPHIC ROCKS

GENERAL STATEMENT

The metamorphic rocks of the Mascoma quadrangle consist of a great number of lithologic types, of sedimentary and volcanic origin. They range in age from Middle Ordovician (?) to Lower Devonian (Fig. 2). Except for a small area of high-grade schists in the southeastern part of the quadrangle, they all belong to the middle-grade zone of metamorphism.

ORFORDVILLE FORMATION

Correlation.—The Orfordville formation was named by Hadley (1938) for a group of black schists and volcanics, which underlie the Albee formation in the Mt. Cube quadrangle. This formation consists of a lower volcanic member, the Post Pond volcanics, and an overlying series of black schists, in the middle of which is the relatively thin Hardy Hill quartzite member (Fig. 2).

Black schists.—The black schists which lie above the Post Pond volcanics are continuous with identical types studied by Hadley in the Mt. Cube quadrangle, and are represented on the geological map (Pl. 6) by the letter symbol *Oo*. They are fine-grained, thinly-bedded rocks with a well-marked schistosity. Field and laboratory studies show that, although all transitions exist, they may be classified as quartzite, quartz-mica schist, mica-quartz schist, and mica schist.[1] Interbedded with these schists are small lenses of volcanic material, one of which, near Etna Highlands School in Hanover Township, is large enough to map. Several modes of the black schists are given in Table 1.

Quartzite, though uncommon, occurs as a fine-grained, dark gray rock possessing only a slight trace of cleavage.

Mica-quartz schist is abundant. It contains biotite porphyroblasts which lie at all angles to the schistosity. The biotite contains inclusions of fine carbonaceous material in streaks and bands which probably represent bedding. The highly crumpled character of the rock is well shown by wavy bands of these inclusions (Pl. 4, fig. 1). Garnet occurs in small euhedral crystals, in rounded grains, and in large skeletal crystals nearly a centimeter across (Pl. 4, fig. 2). Its specific gravity is 4.15, and its refractive index is 1.806 $\pm$ 0.003. The composition, therefore, is almandite. The schists are black due mainly to the presence of about one per cent of finely divided carbonaceous material.

Mica schist differs from the mica-quartz schist only in having more mica and a better schistosity.

Hardy Hill quartzite.—The name Hardy Hill quartzite is proposed for the quartzite and quartz conglomerate member near the top of the Orfordville formation. The thickness of this member ranges from 0 to 250 feet. The cause of the great variation in thickness within short distances is

[1] For convenience in nomenclature metamorphic rocks consisting largely of mica and quartz, with some feldspar, are classified as follows: (1) mica schist, less than 60 per cent quartz and feldspar; (2) mica-quartz schist, 60 to 80 per cent quartz and feldspar; (3) quartzite and quartz-mica schist, over 80 per cent quartz and feldspar.

TABLE 1.—*Modes of the Orfordville fo*

	Black Schists						Post Pond Metamorphosed Volcanics						
	1	2	3	4	5	6	7	8	9	10	11	12	13
Large Crystals:*													
Quartz	.....	.....	.....	.....	.....	.....	15	.....	.....	.....	.....	.....	.....
Oligoclase	.....	.....	.....	.....	.....	.....	20	.....	.....	5	.....	.....	.....
Porphyroblasts:													
Oligoclase	10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Biotite	.....	.....	2	10	9	.....	.....	.....	.....	.....	.....	.....	.....
Hornblende	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1	20	.....
Garnet	.....	.....	2	.....	.....	20	.....	.....	.....	.....	.....	.....	.....
Kyanite	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Groundmas:													
Quartz	55	70	65	47	55	65	20	35	33	30	7	10	20
Microcline	.....	.....	.....	.....	.....	.....	43	25	.....	.....	.....	.....	.....
Oligoclase	.....	.....	.....	.....	.....	.....	.....	15	40	40	50	42	45
Muscovite	26	4	15	25	33	.....	1	15	17	5	.....	.....	.....
Biotite	.....	15	8	12	.....	.....	tr.	2	.....	10	.....	.....	13
Chlorite	8	2	5	.....	.....	11	.....	.....	.....	3	15	15	.....
Calcite	.....	.....	.....	.....	.....	.....	.....	3	8	.....	12	7	.....
Epidote	tr.	.....	.....	.....	.....	.....	.....	4	.....	tr.	15	3	20
Garnet	.....	7	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Carbon	1	2	1	3	2	1	.....	.....	.....	.....	.....	.....	.....
Hornblende	.....	.....	.....	.....	.....	tr.	.....	.....	.....	.....	.....	.....	.....
Kyanite	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Tourmaline	tr.	tr.	.....	tr.	tr.	.....	.....	1	.....	.....	.....	.....	1
Magnetite	tr.	tr.	1	.....	tr.	3	.....	.....	.....	.....	.....	3	1
Sphene	tr.	.....	.....	.....	.....	.....	tr.	.....	tr.	tr.	.....	.....	.....
Zircon	tr.	tr.	tr.	tr.	tr.	tr.	.....	.....	.....	.....	.....	.....	.....
Pyrite	.....	.....	.....	3	.....	.....	tr.	tr.	2	7	tr.	.....	.....
Apatite	.....	.....	.....	.....	.....	.....	.....	.....	tr.	tr.	.....	.....	.....
Rutile	.....	.....	.....	.....	.....	.....	tr.	.....	.....	.....	.....	.....	.....
Structure	S	S	S	S	S	S	G	S	S	G	S	G	S
Size, Large Crystals in mm.							0.50–5.00	.....	.....	0.20–1.00	.....	.....	.....
Size, Porphyroblasts in mm.	0.10–0.70	.....	0.50–1.50	0.10–0.40	0.10–0.50	0.50–2.00	.....	.....	.....	.....	0.10–3.00	0.50–10.00	.....
Size, Groundmass in mm.	0.01–0.05	0.01–0.10	0.01–0.03	0.01–0.02	0.01–0.03	0.02–0.10	0.02–0.05	0.03–0.20	0.02–0.20	0.02–0.10	0.02–0.15	0.02–0.05	0.02–0.30

* Includes large crystals or fragments of intratelluric origin which were deposited with the original volcanics. G = Granoblastic. S = Schistose.

1. Mica-quartz schist from elevation 1360 feet three-quarters of a mile south of North Neighborhood School in Hanover.
2. Mica-quartz schist from elevation 1000 feet east of the "S" in "Signal Hill" in Lebanon.
3. Mica-quartz schist from one-quarter mile southwest of the "A" in "LEBANON."
4. Mica schist from near road half a mile west of Potato Hill School in Enfield.
5. Mica schist from one mile southwest of North Neighborhood School in Hanover.
6. Garnet-chlorite schist from elevation 1150 feet five-eighths of a mile southeast of Hardy Hill School in Lebanon.
7. Quartz-oligoclase-microcline gneiss from near north boundary of area, one mile east of the Connecticut River.
8. Quartz-oligoclase-microcline schist from northernmost knoll of Signal Hill in Lebanon.
9. Quartz-oligoclase-muscovite schist from road-cut a mile east of Lebanon village.
10. Quartz-oligoclase-biotite-muscovite schist from near side road three-quarters of a mile southwest of Hayes Hill.
11. Quartz-oli
12. Quartz-oli Cemete
13. Quartz-oli
14. Amphibol
15. Quartzite
16. Feldspath in Plain
17. Mica-quar in Hanc
18. Mica-quar Hanove
19. Mica-quar in Hanc
20. Mica-quar Hanove
21. Mica-quar
22. Mica schi
23. Kyanite s in Leba
24. Kyanite s

TABLE 1

Black Schists						P	
1	2	3	4	5	6	7	
.....	.....	.....	.....	.....	.....	15	..
.....	.....	.....	.....	.....	.....	20	..
10	.....	.....	.....	.....	.....	.....	..
.....	.....	2	10	9	.....	.....	..
.....	.....	.....	.....	.....	.....	.....	..
.....	.....	2	.....	.....	20	.....	..
.....	.....	.....	.....	.....	.....	.....	..
55	70	65	47	55	65	20	
.....	.....	.....	.....	.....	.....	43	
.....	.....	.....	.....	.....	.....	.....	
26	4	15	25	33	.....	1	
.....	15	8	12	.....	.....	tr.	
8	2	5	.....	.....	11	.....	..
.....	.....	.....	.....	.....	.....	.....	
tr.	.....	.....	.....	.....	.....	.....	
.....	7	.....	.....	.....	.....	.....	..
1	2	1	3	2	1	.....	..
.....	.....	.....	.....	.....	tr.	.....	..
.....	.....	.....	.....	.....	.....	.....	..
tr.	tr.	.....	tr.	tr.	.....	.....	..
tr.	tr.	1	.....	tr.	3	.....	..
tr.	.....	.....	.....	.....	.....	tr.	..
tr.	tr.	tr.	tr.	tr.	tr.	.....	..
.....	.....	.....	3	.....	.....	tr.	..
.....	.....	.....	.....	.....	.....	.....	..
.....	.....	.....	.....	.....	.....	tr.	..
S	S	S	S	S	S	G	
						0.50–5.00	..
0.10–0.70	.....	0.50–1.50	0.10–0.40	0.10–0.50	0.50–2.00	.....	..
0.01–0.05	0.01–0.10	0.01–0.03	0.01–0.02	0.01–0.03	0.02–0.10	0.02–0.05	0.

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lcanics. G = Granoblastic. S = Sch

ist from elevation 1360 feet three-quarters of
ghborhood School in Hanover.
ist from elevation 1000 feet east of the "S" in

ist from one-quarter mile southwest of the "

n near road half a mile west of Potato Hill Sch
one mile southwest of North Neighborhood Scho
schist from elevation 1150 feet five-eighths of a
School in Lebanon.
e-microcline gneiss from near north boundary
he Connecticut River.
e-microcline schist from northernmost knoll of

e-muscovite schist from road-cut a mile eas

e-biotite-muscovite schist from near side road
hwest of Hayes Hill.

TABLE 1.—*Modes of the Orfordville formation*

	Post Pond Metamorphosed Volcanics								Post Pond Metamorphosed Sediments									
6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
....	15	.....	.....	.....	.....	.....	.....	.....	10	.....	.....	.....	.....	.....	.....	.....	.....	12
....	20	.....	.....	5	.....	.....	.....	.....	5	.....	5	.....	.....	3	.....	.....	.....	.....
....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	2	.....	9	.....	.....
20	.....	.....	.....	.....	1	20	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	35	7
65	20	35	33	30	7	10	20	5	72	55	57	65	42	50	45	60	60	43
....	43	25	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
....	.....	15	40	40	50	42	45	25	5	30	5	7	25	22	25	tr.	.....	5
....	1	15	17	5	.....	.....	.....	.....	.....	7	30	7	.....	23	9	30	5	15
....	tr.	2	.....	10	.....	.....	13	.....	3	tr.	tr.	17	15	.....	18	.....	.....	.....
11	.....	.....	.....	3	15	15	.....	3	5	7	1	3	15	.....	tr.	1	.....	17
....	.....	3	8	.....	12	7	.....	10	.....	tr.	.....	.....	.....	.....	.....	.....	.....	.....
....	.....	4	.....	tr.	15	3	20	20	.....	.....	.....	.....	1	tr.	tr.	.....	.....	tr.
....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	tr.	1	.....	2	tr.	.....	.....
1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
tr.	.....	.....	.....	.....	.....	.....	.....	37	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
....	.....	1	.....	.....	.....	.....	1	.....	.....	.....	.....	1	.....	.....	.....	.....	.....	.....
3	.....	.....	.....	.....	.....	3	1	.....	.....	.....	.....	tr.	1	tr.	1	tr.	.....	.....
....	tr.	.....	tr.	tr.	.....	.....	.....	tr.	.....	tr.	tr.	.....	tr.	tr.	.....	.....	.....	tr.
tr.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	tr.	tr.	.....	.....	tr.	.....	.....	.....
....	tr.	tr.	2	7	tr.	.....	.....	.....	tr.	.....	tr.	.....	.....	.....	.....	.....	.....	.....
....	.....	.....	tr.	tr.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	tr.	.....	.....	.....
....	tr.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	tr.	tr.
S	G	S	S	G	S	G	S	S	G	S	S	S	S	S	S	S	S	S
	0.50–5.00	.....	.....	0.20–1.00	.....	.....	.....	.....	0.10–0.50	.....	.....	.....	.....	0.20–0.80	.....	.....	.....	0.50–1.50
.50–.00	.....	.....	.....	.....	0.10–3.00	0.50–10.00	.....	.....	.....	.....	.....	.....	.....	0.20–0.80	.....	0.10–1.50	1.00–15.00	0.50–1.50
.02–.10	0.02–0.05	0.03–0.20	0.02–0.20	0.02–0.10	0.02–0.15	0.02–0.05	0.02–0.30	0.01–0.30	0.01–0.05	0.01–0.10	0.03–0.30	0.03–0.10	0.02–0.08	0.01–0.05	0.03–0.10	0.02–0.07	0.03–0.40	0.01–0.03

origin which were deposited
S = Schistose.

ee-quarters of a mile south

of the "S" in "Signal Hill"

west of the "A" in "LEB-

otato Hill School in Enfield.
nborhood School in Hanover.
e-eighths of a mile southeast

rth boundary of area, one

most knoll of Signal Hill in

t a mile east of Lebanon

ar side road three-quarters

11. Quartz-oligoclase-biotite schist from brook near Hough School in Lebanon.
12. Quartz-oligoclase-hornblende schist from hill one mile northwest of Gleason Cemetery in Plainfield.
13. Quartz-oligoclase-biotite schist from Mink Brook at Etna.
14. Amphibolite from just east of the "E" in "LEBANON."
15. Quartzite from hill half a mile northeast of Gleason Cemetery in Plainfield.
16. Feldspathic quartzite from hill one-eighth of a mile north of Gleason Cemetery in Plainfield.
17. Mica-quartz schist from elevation 1300 feet half a mile southwest of Hayes Hill in Hanover.
18. Mica-quartz schist from near road one mile due east of Pinneo School in Hanover.
19. Mica-quarts schist from brook one-quarter of a mile east of Pinneo School in Hanover.
20. Mica-quarts schist from hill three-quarters of a mile west of Arvin School in Hanover.
21. Mica-quarts schist from brook near Pinneo School in Hanover.
22. Mica schist from elevation 1000 feet on Bass Hill in Lebanon.
23. Kyanite schist from one-quarter of a mile south of the "S" in "Signal Hill" in Lebanon.
24. Kyanite schist from elevation 1140 feet near the "F" in "PLAINFIELD."

in part sedimentary and in part structural. The member consists predominantly of gray to white quartzite and quartz conglomerate, with minor amounts of interbedded quartz-mica schist and mica schist. Bedding planes are conspicuous; the individual beds range from a few inches to a few feet in thickness. The conglomeratic character is not always well shown because the pebbles have about the same composition as the matrix, and recrystallization has been intense. The pebbles which are from one to three inches long are composed of nearly pure vein quartz and quartzite, and have been greatly deformed during folding and metamorphism.

Post Pond volcanics.—The name Post Pond volcanics is given by Hadley (1938) to the rocks, mostly metamorphosed volcanics, which occur in the lower part of the Orfordville formation in the Mt. Cube quadrangle. In the Mascoma quadrangle the Post Pond member consists of metamorphosed sediments as well as metamorphosed volcanics.

The metamorphosed volcanics are medium to fine-grained gneiss and schist, probably derived from volcanic tuff. No true lava flows were observed. The following lithologic types are present: (1) quartz-oligoclase-microcline gneiss and schist (originally rhyolite), (2) quartz-oligoclase-biotite-muscovite schist (originally quartz latite), (3) quartz-oligoclase-biotite schist (originally dacite), and (4) amphibolite (originally basalt). Several modes are given in Table 1.

The quartz-oligoclase-microcline gneiss and schist, originally rhyolite, are light colored rocks. Large crystals of quartz and albite-oligoclase (intratelluric phenocrysts), up to half a centimeter long, constitute 25 per cent of these rocks. The large quartz crystals have been granulated and recrystallized into mosaics. The plagioclase crystals, on the other hand, are fractured and bent, but in a few cases are granulated and recrystallized (Pl. 2, fig. 1). The groundmass is composed of quartz and microcline with very minor amounts of albite-oligoclase.

Quartz-oligoclase-biotite-muscovite schist, originally quartz latite, is abundant. The coarser and more gneissic type has preserved its large crystals better than the schistose type. Intratelluric crystals of quartz, up to four millimeters long, make up 10 per cent of the rock (Pl. 2, fig. 2). Green or red-brown biotite usually occurs in small flakes, but in some specimens it is in large flakes, poikiloblastically enclosing quartz and feldspar.

The quartz-oligoclase-biotite schist, originally dacite, is equally common with the quartz-oligoclase-biotite-muscovite schist and closely resembles the latter. Biotite and chlorite are important constituents, whereas muscovite is usually absent. A blue-green hornblende is present in some specimens in slender, euhedral crystals up to one centimeter long. The centers of these crystals are filled with inclusions of feldspar, epidote, and quartz (Pl. 2, fig. 4).

Amphibolite, originally basalt, is relatively scarce in the Post Pond volcanics of the Mascoma quadrangle. It is a medium to fine-grained rock, ranging in color from dark green or gray to black. Blue-green hornblende is the principal dark mineral, and it commonly shows a linear orientation. Oligoclase and epidote constitute most of the rest of the rock.

Among the metamorphosed sediments are the following types: (1) quartzite, (2) mica-quartz schist, (3) mica schist, and (4) kyanite schist. The modes of these rocks are given in Table 1.

The quartzite, though relatively scarce, is in most instances feldspathic. It is fine-grained, gray and locally possesses a poor cleavage.

The mica-quartz schist is fine-grained, and commonly contains 25 per cent of oligoclase or andesine. The biotite is brown, and is considerably altered to chlorite. Poorly formed porphyroblasts up to two millimeters across are seen in some thin sections. Garnet is present in small crystals which contain minute inclusions of quartz and other minerals.

Mica schist is as common as the mica-quartz schist. Reddish-brown biotite may be present either in fine flakes or in porphyroblasts up to two millimeters across. Some specimens contain as much as 20 per cent garnet in small anhedral crystals whose centers are filled with minute inclusions. This rock may be distinguished as garnet-mica schist. In other specimens the high content of calcite justifies the name calcareous mica schist.

Kyanite schist is characteristic of the top of the Post Pond member. It may be subdivided into two types, that with chlorite and that without chlorite. The chloritic type occurs mainly in Plainfield Township, and consists of a fine-grained, muscovite-chlorite schist with 5 or 10 per cent of kyanite. Quartz occurs in small grains (0.03 millimeter) with minor amounts of oligoclase. Rounded quartz grains, many of which are over one millimeter long, are abundant (Pl. 2, fig. 3). These have been slightly granulated and recrystallized. The non-chloritic type on Signal Hill in Lebanon Township, is coarser-grained, and may contain 35 per cent of kyanite in crystals an inch or more in length. Much of the kyanite has been hydrothermally altered to muscovite. In thin section the kyanite crystals show a feathery outline, and poikiloblastically enclose quartz. The groundmass is composed mainly of quartz with smaller amounts of muscovite. The mineralogical composition of these rocks and their association with quartzite and mica-quartz schist strongly favor the idea that the kyanite schist was derived from sediments rich in alumina and extremely low in iron, and, in the case of the non-chloritic type, extremely low in magnesium.

Age.—The Orfordville formation is overlain by the Albee, Ammonoosuc, Partridge, Clough, Fitch, and Littleton formations in ascending order (Fig. 2). The Fitch contains middle Silurian fossils, and the Clough, since it grades into the Fitch, is either lower or middle Silurian. There is an unconformity beneath the Clough (Billings, 1937, p. 483). Billings and Hadley (personal communication) are of the opinion that the Partridge, Ammonoosuc and Albee formations, and certain slates and sandstones in eastern Vermont, which are to be correlated with the Orfordville, overlie the fossiliferous Deepkill and Normanskill (Richardson, 1919, p. 51) of eastern Vermont. Hence the Orfordville is probably upper Middle Ordovician and the Albee and Ammonoosuc Upper Ordovician.

Thickness.—Due to the intense crumpling, it is difficult to measure the true thickness of the Orfordville. The extreme upper part of the formation is cut out by the Northey Hill thrust. It is estimated, however, that the total thickness exposed in the Mascoma quadrangle is 4000 ± 2000 feet. About one-half of this thickness is represented by the Post Pond member and the other half by the black schists and Hardy Hill quartzite member. The Hardy Hill quartzite is absent in some places; elsewhere it is 250 feet thick.

MISSING FORMATIONS

The Albee formation (Billings, 1935, p. 9) which occurs farther northeast, in New Hampshire, is absent in the Mascoma quadrangle, because

of thrust faulting. It is mentioned here, however, to make the stratigraphic column complete. In the middle-grade zone of metamorphism it consists of a thick series (4000 ± feet) of quartzite and schist, and overlies the Orfordville formation and underlies the Ammonoosuc volcanics. As will be shown, most of the Ammonoosuc volcanics and part of the Littleton formation are missing in the Mascoma quadrangle, also for tectonic reasons.

AMMONOOSUC VOLCANICS

Correlation.—The name Ammonoosuc volcanics has been given by Billings (1935, p. 10) to a group of volcanic rocks in the Littleton and Moosilauke quadrangles in western New Hampshire. In the Mt. Cube quadrangle there is a belt of rocks which Hadley has identified from stratigraphic relations and lithologic character as Ammonoosuc volcanics, and which can be traced southward into the Mascoma quadrangle. In view of these facts, certain volcanic rocks of the Mascoma quadrangle are correlated with the Ammonoosuc volcanics which they resemble very closely in the Littleton and Moosilauke areas.

Lithology and petrography.—The rocks of this formation consist essentially of amphibolite with small amounts of biotite gneiss. They are believed to have been derived from volcanic tuffs, breccias, and conglomerates, but it is possible that a few may have been true lavas. Metamorphism has destroyed most of the original textures and structures of these rocks, but in some exposures these still persist. Breccias are found in Dorchester Township, near the bridge over the Mascoma River; farther down the river, some of the rocks still retain their tuffaceous characteristics. Bedded structure expressed by alternating light and dark layers is locally preserved. Modes will be found in Table 2.

Amphibolite constitutes about 80 per cent of the formation. It is a dark, fine to medium-grained rock, composed essentially of hornblende and plagioclase. The hornblende is in needles or stubby crystals many of which poikiloblastically enclose small grains of feldspar. The optics of several specimens of hornblende, given in Table 3, closely resemble those of an analyzed hornblende from the Littleton-Moosilauke area (Billings, 1937, p. 513). The optics and chemical analysis of this hornblende are as follows: $\alpha = 1.654$. $\beta = 1.667$, $\gamma = 1.676$; optically negative; $2V = 71°$; Y = b, $Z \wedge c = 19°$; X = Y = yellowish green, Z = bluish green; X = Y < Z:

SiO_2	44.18
TiO_2	1.23
Al_2O_3	10.34
Fe_2O_3	3.02
FeO	13.90
MnO	tr.
MgO	11.39
CaO	12.31
Na_2O	1.11
K_2O	.81
H_2O	1.57
	99.86

Feldspar ranges in composition from intermediate andesine to sodic bytownite, and in some sections shows strong zoning. Epidote is not usually a major constituent of the amphibolite, but in some specimens it composes 45 per cent of the rock. Sphene, in some instances, makes up as much as 5 per cent of the rock.

The biotite gneiss is a gray, metamorphosed volcanic rock (mostly dacite), composed essentially of quartz, sodic plagioclase, and biotite, with smaller amounts of garnet, amphibole, and muscovite. Feldspar ranges from intermediate oligoclase to sodic andesine, and is present in round or elongate grains. Biotite is in well-oriented, green or reddish-brown flakes which are usually less than one millimeter across.

TABLE 2.—*Modes of the Ammonoosuc volcanics*

	1	2	3	4	5	6	7	8	9	10	11	12
Phenocrysts:												
Quartz	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	10	.....
Oligoclase	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	25	.....
Labradorite	.....	.....	.....	.....	.....	.....	10	.....	.....	.....	.....	.....
Groundmass:												
Quartz	.....	.....	.....	.....	5	.....	.....	.....	15	35	25	20
Oligoclase	.....	.....	.....	.....	.....	.....	.....	10	65	45	35	.....
Andesine	.....	.....	.....	.....	45	60	.....	.....	.....	.....	.....	60
Labradorite	20	.....	40	50	.....	.....	45	.....	.....	.....	.....	.....
Bytownite	.....	40	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Hornblende	75	60	45	45	45	38	40	45	15	.....	2	1
Muscovite	.....	tr.	.....	.....	.....	.....	tr.	.....	.....	7	.....	.....
Biotite	.....	.....	.....	tr.	tr.	.....	.....	tr.	2	12	2	7
Chlorite	.....	.....	tr.	4	.....	.....	.....	tr.	tr.	tr.	tr.	5
Epidote	2	.....	15	.....	.....	.....	2	45	.....	tr.	tr.	.....
Garnet	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	5
Apatite	.....	.....	.....	.....	tr.	tr.	.....	.....	tr.	1	tr.	tr.
Magnetite	.....	.....	.....	1	.....	1	tr.	.....	.....	.....	.....	tr.
Sphene	1	.....	tr.	.....	4	1	tr.	tr.	.....	.....	1	tr.
Pyrite	.....	.....	.....	.....	tr.	.....	.....	.....	3	tr.	.....	1
Calcite	.....	.....	.....	.....	.....	.....	3	.....	.....	.....	.....	.....
Zircon	.....	.....	.....	.....	.....	.....	.....	.....	tr.	.....	.....	.....
Rutile	.....	.....	.....	tr.	.....	.....	.....	.....	.....	.....	.....	.....
Structure	S	S	S	S	G	S	S	S	G	S	G	G
Size phenocrysts in mm.	.....	.....	.....	.....	.....	.....	1.00–4.00	.....	.....	.....	0.50–4.00	.....
Size groundmass in mm.	0.05–3.00	0.05–5.00	0.05–5.00	0.10–3.00	0.10–3.00	0.10–2.00	0.10–0.50	0.02–0.30	0.03–0.30	0.05–0.30	0.05–0.20	0.10–0.70

G = Granoblastic S = Schistose

1. Amphibolite from near outlet of Crystal Lake in Canaan.
2. Amphibolite from elevation 1120 feet in Mascoma River in Dorchester.
3. Amphibolite from half a mile north of triangulation point on East Hill in Canaan.
4. Amphibolite from main road a mile west of Canaan village.
5. Amphibolite inclusion from hill northeast of Enfield Center.
6. Amphibolite from just south of the "E" in "EAST HILL" in Enfield.
7. Amphibolite from elevation 1180 feet in Mascoma River in Dorchester.
8. Amphibolite from elevation 1950 feet just southeast of North Peak in Hanover.
9. Biotite-hornblende gneiss from brook near the "S" in "Skinner Brook" in Grantham.
10. Biotite gneiss from elevation 2000 feet half a mile northeast of North Peak in Hanover.
11. Biotite gneiss from elevation 1620 feet half a mile northeast of North Peak in Hanover.
12. Biotite gneiss from elevation 1540 feet in brook near the "G" in "GRANTHAM."

Age.—The age has been discussed under the Orfordville formation.

Thickness.—The total thickness of the Ammonoosuc volcanics in the Littleton and Moosilauke quadrangles (Billings, 1935, p. 12) is 2000 feet, but only the upper few hundred feet of the formation are exposed in the

TABLE 3.—*Optical properties of hornblendes of the Ammonoosuc volcanics*

1. From specimen 2 of Table 2		
$\alpha = 1.651$	$r > v$ perc.	X = yellow
$\beta = 1.663$	$2V = 80°–85°$	Y = green
$\gamma = 1.674$	Y = b	Z = greenish blue
Optically (−)	$Z \wedge c = 21°$	$Z > Y > X$
2. From specimen 3 of Table 2		
$\alpha = 1.660$	$r > v$ perc.	X = yellow
$\beta = 1.674$	$2V = 70°–75°$	Y = deep green
$\gamma = 1.681$	Y = b	Z = greenish blue
Optically (−)	$Z \wedge c = 19°$	$Z > Y > X$
3. From specimen 5 of Table 2		
$\alpha = 1.657$	$r > v$ perc.	X = yellow
$\beta = 1.670$	$2V = 80°$	Y = green
$\gamma = 1.680$	Y = b	Z = greenish blue
Optically (−)	$Z \wedge c = 20°$	$Z > Y > X$
4. From specimen 7 of Table 2		
$\alpha = 1.660$	$r > v$ perc.	X = yellow
$\beta = 1.673$	$2V = 80°$	Y = yellowish green
$\gamma = 1.682$	Y = b	Z = greenish blue
Optically (−)	$Z \wedge c = 19°$	$Z > Y > X$
5. From specimen 9 of Table 2		
$\alpha = 1.659$	$r > v$ perc.	X = yellow
$\beta = 1.672$	$2V = 85°$	Y = yellowish green
$\gamma = 1.683$	Y = b	Z = greenish blue
Optically (−)	$Z \wedge c = 20°$	$Z > Y > X$
6. From specimen just north of the "O" in "DORCHESTER"		
$\alpha = 1.650$	$r > v$ perc.	X = yellow
$\beta = 1.663$	$2V = 80°$	Y = green
$\gamma = 1.673$	Y = b	Z = greenish blue
Optically (−)	$Z \wedge c = 20°$	$Z > Y > X$

Mascoma quadrangle due to the intrusion of certain igneous masses. The total thickness of the formation exposed does not exceed 600 feet.

CLOUGH FORMATION

Correlation.—The name Clough formation has been given by Billings (1935, p. 13) to the interbedded quartz conglomerate and quartzite, which underlie the Fitch formation in the Littleton and Moosilauke quadrangles. Similar quartzites and quartz conglomerates, in the Mascoma quadrangle, occupy the same stratigraphic position, and are, therefore, correlated with the Clough formation.

Lithology and petrography.—The Clough formation consists of quartzite and quartz conglomerate interbedded with mica schist. The schist con-

stitutes less than 25 per cent of the formation. The modes of several types are given in Table 4.

TABLE 4.—*Modes of the Clough formation*

	1	2	3	4
Porphyroblasts:				
Albite				12
Garnet			3	2
Groundmass:				
Quartz	97	80	70	60
Oligoclase		12		
Muscovite	3	tr.	15	15
Biotite	tr.	4		9
Chlorite		tr.	8	1
Epidote		2	tr.	tr.
Apatite	tr.		tr.	tr.
Garnet		1		
Zircon	tr.	tr.	tr.	tr.
Magnetite		tr.	4	1
Sphene				tr.
Tourmaline	tr.	tr.	tr.	tr.
Structure	G	G	S	S
Size Porphyroblasts in mm.			0.50–1.50	0.50–4.00
Size Groundmass in mm.	0.10–1.50	0.10–0.40	0.10–0.30	0.10–0.50

G = Granoblastic S = Schistose

1. Quartzite from near top of Moose Mountain east of Ruddsboro School in Hanover.
2. Feldspathic quartzite from elevation 1720 feet north of North Peak in Hanover.
3. Mica-quartz schist from top of Moose Mountain east of Ruddsboro School in Hanover.
4. Feldspathic mica schist from top of Moose Mountain, east of Mascoma village.

The quartz conglomerate is a massive, coarse-grained, white to bluish-gray rock, composed of pebbles up to eight inches long set in a matrix of relatively pure quartzite. The pebbles, chiefly vein quartz and white or gray quartzite, were tremendously distorted during metamorphism.

Microscopic study of the quartzite shows quartz to be inequigranular with granoblastic texture, and the grain-size to range from a few tenths of a millimeter to a few millimeters. The feldspar consists of highly sericitized oligoclase grains molded between the quartz. Biotite, if present, and muscovite are in small, well-orientated flakes.

The mica schist and mica-quartz schist are medium to fine-grained, and consist principally of quartz and muscovite. Biotite, plagioclase and garnet, however, are less abundant. Garnets up to 2 millimeters across contain elongate inclusions of quartz, tourmaline, and magnetite. The discordance between the orientation of the elongated grains in the garnet and those in the schist indicates a slight rotation of these porphyroblasts some time after they had captured their inclusions. Albite may be present in rounded masses 5 millimeters across with irregular and indistinct boundaries, and enclosing grains of quartz, magnetite, tourmaline, muscovite, biotite, and garnet.

Age.—Billings (1935, p. 15) concludes that the Clough is of middle or lower Silurian age, since it underlies the Fitch formation, which contains middle Silurian fossils, and because it is separated from the underlying formations by an unconformity.

Thickness.—Billings (1935, p. 15) considers the original thickness of the Clough, in the Littleton and Moosilauke quadrangles, to range from 0 to 150 feet. Hadley (personal communication) believes that southwest along the strike, in the Mt. Cube quadrangle, the thickness varies from 350 to 1200 feet. In the Mascoma quadrangle the maximum thickness is, perhaps, 1200 feet. The minimum thickness, where not cut out by igneous intrusions, is about 200 feet.

FITCH FORMATION

Correlation.—The term Fitch formation was given by Billings (1935, p. 15) to a series of limestones and lime-silicate rocks occurring between the Clough and Littleton formations in the Littleton and Moosilauke quadrangles. This formation can be traced, nearly continuously, southwestward to the Mascoma quadrangle. A group of lime-silicate rocks occurring at this stratigraphic position in the Mascoma quadrangle are correlated with the Fitch formation farther northeast. Only two small patches of the Fitch formation are shown on the geological map; one at the north end of Moose Mountain in Hanover Township, and the other is 1½ miles southwest of Smith Pond in Enfield Township.

Lithology and petrography.—The Fitch formation of the Mascoma quadrangle consists mainly of lime-silicate rocks. These rocks are medium to fine-grained, and are commonly in alternating green and gray bands an inch thick.

The green bands are composed of diopside (33%), epidote (45%), microcline (12%), and a little sphene and magnetite. The diopside has the following optical properties: $\alpha = 1.693$, $\beta = 1.701$, $\gamma = 1.718$; optically positive; $2V = 60°$; dispersion perceptible, $r > v$; $Y = b$, $Z \wedge c = 40°$. According to Winchell (1933, p. 226) the composition would be Di_{80}–He_{20}. The gray bands are rich in microcline which makes up over 50 per cent of the layers. Amphibole is present in crystals 1 to 2 millimeters long and poikiloblastically encloses other minerals. The optics show it to be a hornblende. $\alpha = 1.648$, $\beta = 1.668$, $\gamma = 1.683$; optically negative; $2V = 85°$; dispersion perceptible, $r > v$; $Y = b$, $Z \wedge c = 18°$; X = yellow, Y = yellowish-green, Z = bluish green; $X < Y < Z$. Epidote and diopside are less abundant.

Age.—According to Billings and Cleaves (1934, p. 415), the age of the Fitch formation is Niagaran (Middle Silurian).

Thickness.—The thickness of the Fitch in the Littleton and Moosilauke quadrangles (Billings 1935, p. 16) is calculated to be between 400 and 700 feet. In the Mt. Cube quadrangle, it is somewhat less, and in the Mascoma quadrangle it varies from 0 to 100 feet. Three hypotheses will be considered to explain this apparent thinning of the Fitch formation toward the south.

There may be an unconformity at the base of the Littleton formation. In the Mt. Cube quadrangle the very top of the Fitch formation is characteristically composed of a diopside and actinolite rock. This is the

type of rock present in the Mascoma quadrangle, and probably represents the extreme upper part of the Fitch formation. Therefore, if the top of the Fitch were deposited to the south as well as to the north, the apparent thinning of the formation can not be explained as being due to an unconformity, since the upper beds would be the first to be removed in the production of such an unconformity.

It is possible that the apparent thinning may be due to a fault. However, since field evidence is lacking such a fault would be purely hypothetical.

The lower part of the Fitch in the Littleton and Moosilauke area contains beds closely resembling the Clough lithologically. Hadley (personal communication) finds evidence in the Mt. Cube quadrangle for assuming that rocks of the Clough lithology were being deposited to the south at the same time that rocks of the Fitch type (lime-silicate rocks) were being deposited farther north. This would suggest that, as one proceeds southward, more and more of the lower part of the Fitch is represented by the Clough facies. Therefore, in the Mascoma quadrangle only the very top beds are of the true Fitch facies. This hypothesis also helps to explain some of the thickening of the Clough formation toward the south, as there the Fitch type of sediment has given place to the Clough type. This hypothesis is considered the best by the writer, and the boundary between the Fitch and Clough formations is mapped on the basis of lithology and not on chronology.

LITTLETON FORMATION

Correlation.—The name Littleton formation has been given by Billings (1935, p. 17) to a series of low-grade, metamorphosed, dark slates and sandstones northwest of the Ammonoosuc thrust, in the Littleton and Moosilauke quadrangles. Two other belts of the Littleton formation, one of medium-grade and the other of high-grade metamorphism, are found to the southeast of the fault. The belt of medium-grade rocks consists of mica, garnet, and staurolite schists, and can be traced from the Moosilauke quadrangle to Cornish, in the Mascoma quadrangle. The schists in the southeastern part of the Mascoma quadrangle are also correlated with the Littleton formation, because they lie in the belt of high-grade rocks which can be traced southward from the Moosilauke quadrangle.

Lithology and petrography.—The rocks of the Littleton formation belong to two zones of metamorphism. The western belt of Littleton is in the middle-grade zone, and is composed dominantly of fine to medium-grained schists most of which contain porphyroblasts of biotite, garnet, and staurolite. Amphibolite sills are common but metamorphosed volcanics occur only sparingly, and were probably originally siliceous tuffs. The eastern belt of schists belongs to the high-grade zone of metamor-

phism, and is composed of coarse-grained rocks with porphyroblasts of garnet and sillimanite. The rocks of the Littleton formation, containing considerable amounts of staurolite and sillimanite, were undoubtedly de-

TABLE 5.—*Modes of the Littleton formation*

	1	2	3	4	5	6	7	8
Porphyroblasts:								
Biotite	5	.....	.....	10	.....	3	3	.....
Garnet	.....	5	.....	.....	.....	.....	1	3
Groundmass:								
Quartz	63	60	65	60	75	55	50	40
Oligoclase	.....	.....	.....	5	.....	.....	.....	.....
Andesine	.....	.....	.....	.....	.....	.....	.....	6
Muscovite	20	15	20	15	15	25	40	25
Biotite	.....	4	.....	.....	1	.....	.....	20
Chlorite	10	15	15	10	8	18	2	.....
Sillimanite	.....	.....	.....	.....	.....	.....	.....	6
Epidote	.....	tr.	.....	.....	.....	tr.	tr.	.....
Apatite	tr.	tr.	.....	tr.	.....	tr.	.....	tr.
Magnetite	.....	1	.....	tr.	tr.	2	3	.....
Ilmenite	2	.....	tr.	.....	.....	.....	.....	tr.
Sphene	.....	.....	tr.	.....	.....	.....	.....	tr.
Garnet	.....	.....	.....	tr.	.....	tr.	.....	.....
Zircon	.....	tr.	.....	tr.	.....	.....	.....	.....
Tourmaline	tr.	tr.	tr.	tr.	tr.	tr.	.....	tr.
Structure	S	S	S	S	S	S	S	S
Size Porphyroblasts in mm.	0.50–3.00	0.10–0.30	.....	0.50–1.20	.....	0.50–1.50	0.50–1.50	1.00–1.50
Size Groundmass in mm.	0.02–0.20	0.02–0.05	0.02–0.10	0.05–0.20	0.02–0.07	0.03–0.15	0.01–0.10	0.10–1.00

S = Schistose.

1. Mica-quartz schist from brook east of the "H" in "SHAKER MOUNTAIN."
2. Mica-quartz schist from trail due west of Hyde Hill in Plainfield.
3. Mica-quartz schist from hill one mile northwest of Hyde Hill in Plainfield.
4. Mica-quartz schist from near BM 1167 northwest of Montcalm School in Plainfield.
5. Mica-quartz schist from near road-fork north of Ruddsboro School in Hanover.
6. Mica schist from near the "E" in "SHAKER MOUNTAIN."
7. Mica schist from road-cut one mile west of Enfield village.
8. Sillimanite schist from half a mile south of the "D" in "SPRINGFIELD."

rived from sediments relatively rich in alumina and poor in alkalis, whereas the biotite and garnet rocks were probably originally more normal shales and impure sandstones. Several modes are given in Table 5.

Quartzite is relatively scarce in the Littleton formation. It is fine-grained, ranging in color from white to buff or gray. The mica-quartz schist is fine-grained, medium gray, and constitutes a large percentage of the Littleton formation. Some types possess a perfect cleavage, whereas others split with a more irregular fracture. Chlorite and micas may be uniformly distributed through the quartz mosaic or concentrated into bands and layers. Biotite commonly occurs as porphyroblasts a millimeter across, oriented at all angles to the schistosity; and garnet appears in crystals ranging up to a millimeter in diameter, but it is not an abundant constituent. Mica schist is probably as abundant as the mica-quartz schist, and closely resembles the latter.

Staurolite schist makes up much of the Littleton formation from Shaker Mountain to Cornish Township. The rock is medium to fine-grained resembling the mica schist but with porphyroblasts of staurolite up to several inches in length. The staurolite makes up about 15 per cent of the rock and usually contains abundant inclusions of quartz and magnetite. As a result of alteration, most of the crystals are enclosed in a thick shell of secondary muscovite and chlorite (Pl. 3, fig. 1). There is a marked increase in the size of the porphyroblasts from west to east.

There is a volcanic member near the top of the Littleton formation, which extends from near the crest of Shaker Mountain to Methodist Hill. This member has a maximum thickness of about 300 feet, and is composed of fine to medium-grained, buff colored biotite gneiss (probably originally volcanic tuff) the composition of which ranges from rhyolite to quartz latite.

The rocks of high-grade metamorphism include medium to coarse-grained mica schist and mica-quartz schist many of which contain sillimanite. The coarseness of grain marks these rocks as distinct from those of middle-grade metamorphism. Quartz grains are irregular and show slight straining. Calcic oligoclase or sodic andesine is present in small amounts, but muscovite makes up 25 or 30 per cent of the rock. Biotite is nearly as abundant, and occurs in red-brown flakes a millimeter across. In hand specimen, crystals of sillimanite are abundant; and attain the length of several millimeters. In thin section, the sillimanite appears in sheaves of fine needles a few tenths of a millimeter long, and replaces mica and garnet. Garnet usually constitutes less than 5 per cent of the rock.

Age.—Billings and Cleaves (1934, p. 419) have shown the Littleton to be of Oriskany (Lower Devonian) age.

Thickness.—It is almost impossible to calculate the thickness of the Littleton formation with any degree of accuracy as the detailed structure of it is unknown in most of the area. A rough estimate would be 4000 feet; but it should be noted that this estimate does not represent the total thickness of the formation, as the upper part is cut out by the Northey Hill thrust.

PLUTONIC, SILL, AND DIKE ROCKS

GENERAL STATEMENT

Intrusive igneous rocks constitute about half the rocks of the Mascoma quadrangle. They are nearly all medium to coarse-grained, plutonic gneisses, ranging in composition from granite to quartz diorite. The relative abundance of each of these rock types is estimated to be as follows, in decreasing order: granodiorite, quartz monzonite, quartz diorite, and granite. These gneisses may be divided into two groups, on the basis of age; an older, belonging to the Oliverian magma series, and a younger, belonging to the New Hampshire magma series. A few small bodies of intrusive rocks are younger than the gneisses and belong to the White Mountain magma series.

OLIVERIAN MAGMA SERIES

Correlation.—The term Oliverian magma series was given by Billings (1935, p. 26) to a series of intrusive rocks in the Moosilauke quadrangle, which occurs in a domical structure (Owls Head dome), and is younger than Lower Devonian, but older than the period of folding. Six similar

domes, with the same igneous series, have been studied in western New Hampshire since the original mapping of the Owls Head dome. The distribution of only the completely mapped bodies of this series may be seen in Figure 3. In the Mascoma quadrangle the plutonic rocks of the Mascoma, Smarts Mountain, Croydon, and Lebanon domes belong to the Oliverian magma series.

Mascoma group.—The term Mascoma group is proposed for the plutonic rocks of the Mascoma dome. This group occupies the central part of the Mascoma quadrangle, and consists of fine- to medium-grained, gray rocks. Where considerable potash feldspar is present, however, the rock may be sub-porphyritic with a light pink color. Most specimens show a foliation due to parallel arrangement of small biotite flakes. The composition of the group ranges from quartz diorite to granite, and the areal distribution of these various types is shown on the geological map (Pl. 6). The dotted boundaries indicate that the types are somewhat gradational. Modes are given in Table 6.

Quartz diorite includes the finest-grained types, many of which are border phases. Plagioclase (An_{12} to An_{30}) and quartz constitute most of the rock and give it a granoblastic structure. Biotite is present in small flakes and usually in minor amounts. One characteristic feature more commonly seen in the quartz diorite than in the other rock types is the presence of granulated and recrystallized quartz phenocrysts.

The granodiorite is the most abundant rock in the Mascoma group. It is slightly coarser than the quartz diorite, and has a little more biotite. There is a tendency for biotite, and euhedral crystals of epidote to segregate into masses about half a centimeter across, so as to give these light-gray rocks a spotted appearance. Some varieties are sub-porphyritic with crystals of microcline up to one centimeter long. A little microcline is also present in the groundmass. Plagioclase has the same composition as in the quartz diorite (An_{12} to An_{30}), and quartz is a little less abundant. Small quantities of myrmekite are present, usually replacing potash feldspar.

The texture and grain size of the quartz monzonite and granite are like those of the granodiorite, but the gneissic structure is less perfectly developed. The pink color of much of the quartz monzonite and granite is due to the abundance of microcline in large crystals, commonly a centimeter long. Upon first glance these crystals appear to be phenocrysts, but detailed study, particularly in thin section, disclosed several lines of evidence which point strongly to the idea that they are metacrysts, introduced subsequent to the consolidation of the original rock. Plagioclase ranges in composition from An_{12} to An_{30}, and quartz constitutes 20 to 35 per cent of the rock. Some of the potash feldspar is replaced by myrmekite which may constitute as much as 10 per cent of the rock.

Smarts Mountain group.—The term Smarts Mountain group is used for the plutonic rocks of the Smarts Mountain dome, most of which is exposed in the Mt. Cube quadrangle. A few square miles of this dome are exposed in the northeastern part of the Mascoma quadrangle. The group consists predominantly of quartz diorite with smaller amounts of granodiorite; both rocks closely resemble their equivalent types in the Mascoma group. (See Table 6.)

Croydon group.—The term Croydon group is proposed for the plutonic mass of the Croydon dome. Only the northwestern part of the Croydon

TABLE 6.—*Modes of the Oliverian magma series*

	Mascoma Group												Croydon Group			Smarts Mtn. Group			Lebanon Group					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Quartz	30	45	37	35	38	35	25	33	25	32	20	27	25	40	35	26	30	30	10	20	20	20	30	35
Microcline	....	....	5	9	15	20	25	30	45	44	50	50	1	2	2	....	5	10	5	....	5	28	55	5
Oligoclase	66	54	55	50	45	43	40	35	25	20	20	20	64	53	58	65	60	55	....	60	33	30	10	30
Andesine	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	25	....	....	....	....	....
Muscovite	tr.	....	....	1	tr.	....	tr.	....	tr.	1	2	tr.	....	tr.	....	....	....	tr.	....	2	....	4	2	3
Biotite	3	2	3	4	2	2	5	1	3	3	6	3	7	5	5	1	5	5	10	15	23	8	1	15
Chlorite	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	....	tr.	....	....	2	....	tr.	....
Epidote	tr.	tr.	tr.	....	....	....	5	1	tr.	tr.	2	tr.	tr.	tr.	tr.	tr.	tr.	....	10	3	12	4	2	12
Calcite	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	5	5	....	....
Hornblende	....	....	....	....	....	....	....	....	....	....	....	....	tr.	....	....	7	....	....	50	....	....	....	....	....
Garnet	....	....	....	tr.	....	....	....	....	....	....	....	....	2	....	....	tr.	....	....	....	....	....	....	....	....
Apatite	....	tr.	tr.	tr.	....	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	....	tr.	tr.	tr.	....	tr.
Sphene	....	tr.	tr.	tr.	....	....	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	....	tr.	tr.	tr.	tr.	....
Magnetite	tr.	tr.	....	tr.	tr.	tr.	....	....	tr.	tr.	....	tr.	....	....	tr.	tr.	tr.	tr.	....	....	....	tr.	tr.	....
Pyrite	....	....	tr.	tr.	....	....	....	....	....	....	tr.	....	....	....	....	....	....	....	tr.	....	....	....	....	....
Zircon	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	....	tr.	tr.	tr.	tr.	....	....	tr.	....	....	tr.	tr.
Rutile	tr.	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Tourmaline	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1	....	....
Allanite	....	tr.	tr.	....	....	tr.	tr.	tr.	....	....	tr.	tr.	tr.	....	....	tr.	....	....	....	....	....	....	....	....

1. Quartz diorite from road three-quarters of a mile north of Washburn corner in Springfield.
2. Quartz diorite from hill one and one-half miles north of Canaan Center.
3. Granodiorite near the "H" in "Shaker Hill" in Enfield.
4. Granodiorite from road three-quarters of a mile north of the triangulation station on East Hill in Canaan.
5. Granodiorite from southeastern knoll on Town Hill in Canaan.
6. Granodiorite from elevation 1260 feet on unimproved road west of Clark Pond in Canaan.
7. Quartz monzonite from road one mile south of Tunis School in Hanover.
8. Quartz monzonite from hill one and three-quarters miles north of Tunis School in Hanover.
9. Quartz monzonite from hill one and three-quarters miles north of Tunis School in Hanover.
10. Granite from top of South Peak in Hanover.
11. Granite from near the second "O" of "MOOSE MOUNTAIN" in Hanover.
12. Granite from near Goss Neighborhood School in Hanover.
13. Quartz diorite from top of hill north of the first "A" in "GRANTHAM."
14. Quartz diorite from elevation 1900 feet three-quarters of a mile south of the "G" in "GRANTHAM."
15. Quartz diorite from road near "H" in "GRANTHAM."
16. Quartz diorite from elevation 1920 feet half a mile north of the "T" in "DORCHESTER."
17. Quartz diorite from elevation 1720 feet one-quarter of a mile south of the second "E" in "DORCHESTER."
18. Quartz diorite from contact southwest of Pollard Hill in Dorchester.
19. Amphibolite (gabbro) from knoll north of the western Hanover reservoir.
20. Quartz diorite from east knoll of Lords Hill in Hanover.
21. Granodiorite from hill three-quarters of a mile northeast of Etna.
22. Quartz monzonite from elevation 1000 feet on western slope of northern knoll of Signal Hill in Lebanon.
23. Granite from southern knoll on Rix Ledges in Lebanon.
24. Inclusion of border gneiss in Lebanon granite from northern knoll of Rix Ledges in Lebanon.

dome is exposed in the Mascoma quadrangle. The rocks of the Croydon group closely resemble those in the Mascoma dome (See Table 6). For the most part, potash feldspar is scarce and, as in the Smarts Mountain group, quartz diorite is the predominating rock type. This type occupies the outer part of the igneous body. Although exposures are poor near the center of the mass a few outcrops of granodiorite and quartz monzonite have been found.

Lebanon group.—The term Lebanon group is proposed for the plutonic rocks of the Lebanon dome, which were originally described by Hitchcock (1877, p. 353) as "protogene gneiss", and were grouped under the general term "Bethlehem gneiss". In a more recent work (1909, pp. 139-186), however, he considered the igneous mass as intrusive into the surrounding metamorphic rocks. More detailed studies of this dome have been made by Merritt (1921, p. 1-36), Goldthwait (1925, p. 7), and Kaiser (1938, p. 27) all three of whom recognize the igneous rocks as an intrusive which domes the surrounding rocks. As the Lebanon group intrudes the Orfordville formation, it is probably younger than Middle Ordovician; and as these igneous rocks have suffered the effects of regional metamorphism, they must be older than the metamorphism. In view of these facts and the marked similarity between the Lebanon dome and other domes, the writer considers the Lebanon group consanguineous with the Oliverian magma series.

There are two more or less distinct igneous rock types in the dome, a coarser-grained granitic core surrounded by a finer-grained, more mafic border-phase. The core-rock is a weakly gneissic, pink granite termed the Lebanon granite. The border-phase is, in general, rather different from the granite; the term "border gneiss", used by Goldthwait and Merritt, will be used here when referring to this rock. As the two types are somewhat gradational near their contacts, they have been separated on the geological map by a dotted boundary. Several modes are given in Table 6.

The border gneiss is dark-gray, medium-grained, and ranges in composition from gabbro to quartz monzonite. In most places it possesses a well developed foliation, but in some localities only a pencil structure is observable. Quartz is granulated, and recrystallized into irregularly shaped grains which are commonly seen to be assembled into bands and streaks. Plagioclase ranges in composition from An_{12} to An_{35}. The crystals are bent, fractured, and granulated, and are filled with abundant inclusions of epidote, calcite, and sericite, all of which are probably alteration products of their host. Microcline is most commonly present in small grains. Flakes of olive-green biotite, 0.5 millimeter across, are segregated with sphene into bands and streaks. Hornblende may take the place of biotite as the dark mineral in the rock, but it usually occurs in amounts subordinate to biotite. There are two areas of amphibole-rich rock which contains up to 50 per cent of this blue-green hornblende. One is on the east slope of Pinneo Hill in Hanover Township, and the other is on the hill north of Hanover reservoir. A mode of the rock from the last named locality is given in Table 6. It was probably originally a gabbro. The feldspar has the composition An_{37}, and is more calcic than any other found in the dome. The optics of the horn-

blende in this amphibolite are as follows: $\alpha = 1.640$, $\beta = 1.655$, $\gamma = 1.667$; optically negative; $2V = 80°$; dispersion perceptible, $r > v$; $Y = b$, $Z \wedge C = 22°$; X = greenish yellow, Y = light green, Z = bluish green; $X < Y < Z$.

The Lebanon granite is medium- to coarse-grained, pink, and commonly subporphyritic. The granite in the Mascoma quadrangle has a poor gneissic structure, principally because of the low biotite content, but just west of Rix Ledges, in the Hanover quadrangle, the granite possesses a more definite foliation. Microcline is the most abundant mineral, and occurs in broken and partly granulated phenocrysts usually less than a centimeter long, or in smaller grains 0.2 to 0.3 millimeter in diameter. The larger crystals are usually perthitic. Only small amounts of plagioclase are found, and this is usually sodic oligoclase. Very little, however, is primary, some having been introduced to form replacement perthite, and some occurring in the myrmekite which replaces potash feldspar. Quartz constitutes about a third of the rock, but biotite, muscovite, and epidote are scarce.

Age of intrusions.—The domes (not including the Lebanon dome) are younger than Lower Devonian, because during the intrusion of their igneous cores, the Littleton formation was displaced. From his work in the Moosilauke quadrangle, Billings (1935, p. 34) concluded that the intrusion of the Owls Head group preceded the period of folding. The author has come to the same conclusion for the other Oliverian domes, and detailed consideration of the effects of regional folding upon these domical structures is given later. The age of the Lebanon dome has been considered in the description of the Lebanon group.

NEW HAMPSHIRE MAGMA SERIES

General statement.—The term New Hampshire magma series was given by Billings (1935, p. 26) to a series of plutonic rocks, usually foliated, and characterized by muscovite and biotite. The series was intruded during the late stages of folding or shortly thereafter. The Bethlehem gneiss of the Mascoma quadrangle belongs to this series.

Bethlehem gneiss.—The term Bethlehem was originally used by C. H. Hitchcock (1877, p. 104-111) for a group of igneous rocks in the township of Bethlehem, N. H. Billings (1935, p. 27) has found it advisable, however, to restrict the term to one particular phase. The largest body of this gneiss extends southwest from the Franconia quadrangle through the eastern part of the Mascoma quadrangle and for an unknown distance into the Sunapee quadrangle (Fig. 3). The total length is at least 65 miles. Along the eastern contact of the gneiss, numerous sills of fine-grained Bethlehem have been intruded into the Littleton formation. These sills, however, are not found more than a few hundred feet from the contact. Along this same contact is a zone of pegmatites which is several thousand feet wide, and confined mainly to the Littleton schists.

The Bethlehem gneiss is a medium- to coarse-grained gneiss, composed essentially of quartz, andesine, microcline, biotite, and a little muscovite. It ranges in composition from granodiorite to granite, and may locally contain phenocrysts of potash feldspar up to four inches in length. The gneiss possesses a foliation brought out principally by the marked orien-

tation of the large mica flakes. The foliation gives place to a lineation in many cases and in places both a good foliation and lineation are present. For modes, see Table 7.

TABLE 7.—*Modes of the Bethlehem gneiss*

	1	2	3	4	5	6	7
Quartz	25	20	30	25	40	40	20
Microcline	9	5	12	3	15	5	35
Andesine	45	54	46	51	30	40	28
Myrmekite	1	1	2	1	tr.	tr.	2
Muscovite	1	tr.	2	2	5	1	1
Biotite	18	18	8	18	8	12	13
Chlorite	.....	tr.	tr.	tr.	tr.	tr.	tr.
Epidote	.....	tr.	.....	tr.	.....	.....	.....
Zircon	tr.	tr.	tr.	tr.	tr.	tr.	tr.
Apatite	tr.	tr.	tr.	tr.	tr.	tr.	tr.
Magnetite	tr.	tr.	.....	tr.	.....	.....	1
Ilmenite	.....	.....	.....	.....	.....	tr.	.....
Sphene	.....	.....	.....	.....	.....	tr.	.....
Pyrite	.....	tr.	tr.	.....	.....	.....	.....
Rutile	.....	tr.	.....	.....	.....	.....	.....
Allanite	.....	tr.	.....	tr.	.....	tr.	.....

1. Granodiorite from just east of the Height of Land School in Grafton.
2. Granodiorite from elevation 1120 feet in brook a mile north of Canaan village.
3. Granodiorite from knoll about half a mile west of the outlet of Grafton Pond.
4. Granodiorite from near side road north of Crystal Lake in Canaan.
5. Granodiorite from trail a mile southeast of Leavitt Pond in Grantham.
6. Granodiorite from top of hill east of Spectacle Pond in Enfield.
7 Quartz monzonite from top of knoll northeast of Grass Pond in Grantham.

The texture is inequigranular, and it is common to find the quartz segregated into lenses composed of many individual grains showing strain shadows. These lenses probably represent large crystals which have been slightly granulated and recrystallized. The plagioclase is sodic andesine (An_{30} to An_{40}). Microcline occurs in phenocrysts or as irregular grains in the groundmass, and is commonly replaced by myrmekite. Biotite is abundant in large, red-brown flakes up to 4 millimeters across. It characteristically contains numerous inclusions of zircon, allanite, and epidote, about which are strong pleochroic halos. Associated with biotite aggregates are flakes of muscovite.

Pegmatites.—Genetically related to the Bethlehem gneiss are pegmatites which occur within the igneous rock itself and the surrounding metamorphic rocks. Among those occurring in the igneous rock there are three types; segregation pegmatites, pegmatites associated with sheer zones, and vein pegmatites.

The segregation pegmatites are usually small, irregular masses a few inches across, but some are several feet wide. They are composed dominantly of microcline and quartz with minor amounts of muscovite. A little biotite and black tourmaline have been found.

Pegmatites associated with shear zones have been observed only in a few places. Perhaps the best examples are seen on the series of knobs which extends southward from Halfmile Pond, in Enfield Township. Here the shear zones are a few feet long and two or three inches wide. The relative displacement along these shears is revealed by the drag effect in the biotite layers of the gneiss. In many zones biotite is con-

centrated near the margins, and is in all cases scanty in the centers. The centers of these zones are filled with a mixture of quartz, microcline, and plagioclase, whose grain size is several times that of the surrounding Bethlehem gneiss. It may be assumed that during the consolidation of the igneous rock there was shearing which developed fractures in the semi-solid mass. During this shearing the biotite layers were dragged around into a new position, and pegmatitic juices, from the nearby wall-rock, filled the openings.

Vein pegmatites in the Bethlehem are numerous only in certain localities, one of which is on the hill just east of Spectacle Pond, in Grafton Township. Here pegmatite veins up to 10 or 20 feet wide strike east-west at right-angles to the gneissic structure of the enclosing rock. They are composed essentially of microcline, quartz, muscovite, and biotite. Minor amounts of black tourmaline, beryl, and garnet were seen. These vein pegmatites have never been worked commercially to any extent, perhaps, because of the abundance of larger bodies in the adjacent schists.

There is a broad zone of pegmatites several thousand feet wide in the high-grade Littleton schists near the contact with the Bethlehem. Along this belt, which extends for some distance northeast into the Cardigan quadrangle, are located some of the well-known pegmatite mines of New Hampshire. Several of these are still operating. In the Mascoma quadrangle, however, none of the pegmatites have been very productive. The individual bodies are elongate or irregular masses, usually a few tens of feet wide and a few hundred feet long. The largest of these, several hundred feet across, is on Aaron Ledge in Springfield Township. No detailed study of these pegmatites was made, but they consist predominantly of microcline-perthite and quartz (sometimes as graphic granite) with minor amounts of muscovite, biotite, plagioclase, black tourmaline, apatite, garnet, and beryl.

Age of intrusion.—The Bethlehem gneiss is younger than Lower Devonian because it is intrusive into Littleton schists of Lower Devonian age. From the lead-uranium ratio Shaub (1938, p. 339) has given the age for uraninite from a pegmatite in the Littleton schists two miles east of Spectacle Pond in Enfield Township, as 304 million years (late Devonian). Since this pegmatite is but one of the many genetically related to the Bethlehem gneiss, any data regarding its age is very helpful in determining the age of the gneiss itself. Considering the relatively short period between the intrusion of the gneiss and the subsequent formation of pegmatites, the writer believes that this age determination indicates that the Bethlehem gneiss was intruded during the late Devonian. The position of the intrusion in the sequence of tectonic events will be considered in the discussion of the Mt. Clough pluton.

WHITE MOUNTAIN MAGMA SERIES

Those igneous rocks younger than the New Hampshire magma series and possessing marked alkaline affinities belong to Billings' (1934, p. 56) "White Mountain magma series". In the Mascoma quadrangle, this alkaline suite is represented, for the most part, by numerous dikes which will be considered later. In Dorchester Township, however, there are two small intrusives, both of which belong to this magma series. One is a small stock of quartz syenite, and the other is probably a volcanic pipe.

Only one outcrop of the quartz syenite is seen along the road, southwest of the "P" in "Pollard Hill." The rock, in most places, has been highly disintegrated and the residual soil produced thereby is very distinct from any of the surrounding glacial drift. It is possible to get a general idea of the distribution of the parent rock by observing the distribution of this weathered material. In unweathered specimens this

even-grained, quartz syenite has a greenish appearance, but most of the rock is highly stained with limonite. About 80 per cent of the rock is made up of perthite and antiperthite. The crystals are 2 or 3 millimeters long, and their interstices are filled with quartz, which constitutes about 12 per cent of the rock. The rock also carries about 5 per cent of biotite and small amounts of hastingsite, pyrite, zircon, fluorite, sphene, magnetite, and apatite.

The volcanic breccia, three-quarters of a mile south of the second "R" in "DORCHESTER," was probably formed in a small volcanic pipe, the diameter of which is not much more than one hundred feet. About 50 per cent of the rock is black, aphanitic groundmass composed chiefly of alkali feldspar, hastingsite, biotite, and magnetite. The rest of the rock consists of large phenocrysts of microcline, perthite, plagioclase, quartz, and basaltic hornblende and abundant inclusions of Ammonoosuc volcanics, quartz syenite, and quartz diorite from the Smarts Mountain dome. Many of these inclusions are a foot across. A similar but more extensive breccia is described by Modell (1936, p. 1910) from the Belknap Mountains, New Hampshire.

SILLS AND DIKES

Most of the pre-metamorphism sills are amphibolite. They are common in the Littleton formation, less common in the Clough formation, and rare in the Orfordville formation. They are a few feet wide, and are composed chiefly of amphibole and plagioclase. Their original composition was probably that of basalt.

Pre-metamorphism dikes are uncommon, and only one was studied in thin section. This dike cuts the Mascoma group northeast of North Canaan School, in Canaan Township. The rock is a light-green porphyry with phenocrysts of hornblende a centimeter long. These have been somewhat broken and recrystallized by metamorphism. The phenocrysts constitute about 25 per cent of the rock, but small crystals of the same mineral also make up about 35 per cent of the groundmass. Augite, in crystals 0.5 millimeter long, constitutes 25 per cent of the rock. Epidote is found in small crystals enclosed in the hornblende, or in slightly larger grains in the groundmass. Very minor amounts of microcline and andesine are present.

The post-metamorphism dikes include several distinct types, all of which are believed to belong to the White Mountain magma series. The following types are recognized: (1) olivine diabase, (2) troctolite, (3) camptonite, (4) bostonite, and (5) microgranite porphyry. Modes are given in Table 8.

STRUCTURE

GENERAL STATEMENT

The structure of the Mascoma quadrangle is a sample of the architecture of the belt of gneisses and schists which extends in a north-northeasterly direction through western New Hampshire (Fig. 3). The sedimentary and volcanic rocks, of middle Paleozoic age, have been folded, metamorphosed, and intruded, so that the structure is now exceedingly complicated. The various structural features of the area will be considered in chronological order. The oldest major features are the Oliver-

ian domes, three of which are located along the axis of the Bronson Hill anticline. These will be considered first, and the Lebanon dome, to the west of the anticline, will be described separately. Although the Lebanon

TABLE 8.—*Modes of post-metamorphism dikes*

	1	2	3	4	5	6
Phenocrysts:						
Quartz						15
Perthite					25	10
Antiperthite					5	
Oligoclase						15
Labradorite		3	7			
Oxyhornblende				7		
Apatite				tr.		
Sphene				1		
Groundmass:						
Quartz					5	20
Orthoclase						18
Albite						20
Albite-Oligoclase					59	
Oligoclase		60		53		
Andesine	65					
Labradorite			58			
Augite	10	10				
Oxyhornblende				20		
Hastingsite					tr.	
Biotite	4	2	5		tr.	2
Chlorite	4	5	5	1	1	
Serpentine	11	10	10	3		
Magnetite	5	5	4	4	tr.	
Hematite					1	
Ilmenite					1	
Pyrite	tr.		1			
Sphene	1	3	7	4		tr.
Zircon	tr.				tr.	tr.
Apatite		tr.		tr.		tr.
Calcite		2	3	7	3	
Fluorite					tr.	tr.
Texture	O	O	H	P	T	A
Size Phenocrysts in mm.		1.0–5.0	1.0–2.0	1.0–5.0	0.5–5.0	0.5–3.0
Size Groundmass in mm.	0.5–1.0	0.1–1.0	0.1–1.0	0.1–0.4	0.1–0.3	0.05–0.1

H = hypidiomorphic O = ophitic T = trachytic
A = allotriomorphic P = poikilitic

1. Medium-grained olivine diabase; average 3 thin sections.
2. Fine-grained olivine diabase; average 3 thin sections.
3. Troctolite; average 2 thin sections.
4. Camptonite; 1 thin section
5. Bostonite; 1 thin section.
6. Microgranite porphyry; 1 thin section.

dome is probably of about the same age as the other domes, there are many differences which justify its separate treatment here. After considering these domes, the Salmon Hole Brook syncline, in the western

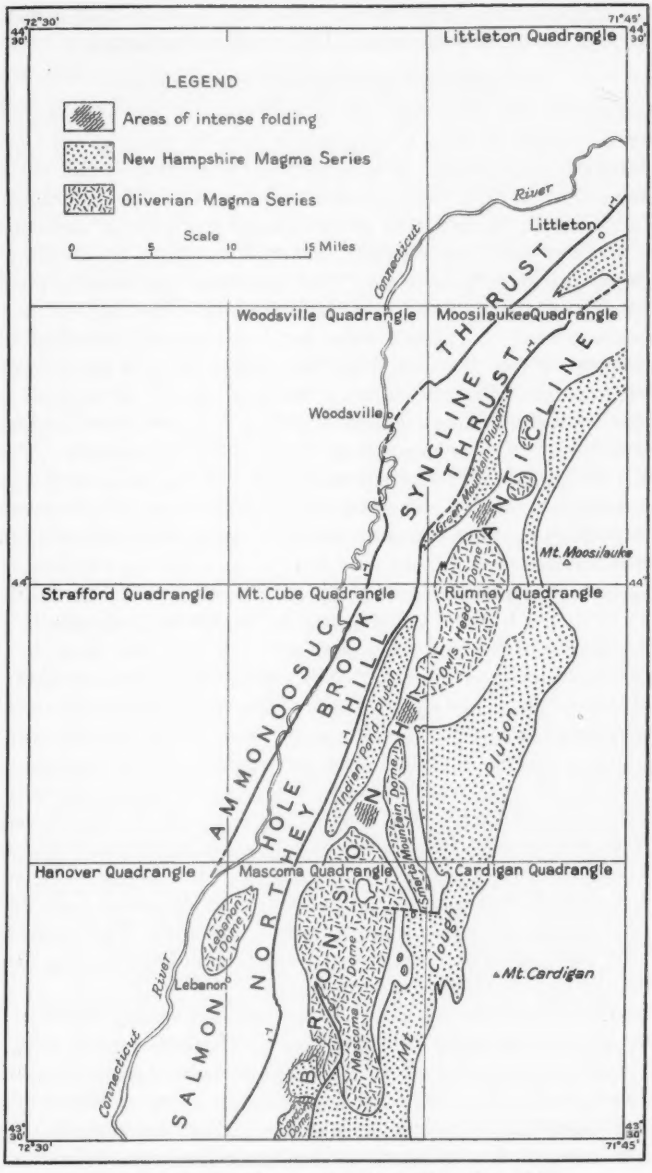


FIGURE 3.—*Structural units of western New Hampshire*

part of the area, will be described. Then the Northey Hill thrust, the Mt. Clough pluton, and the normal faults will be considered.

OLIVERIAN DOMES OF BRONSON HILL ANTICLINE

Mascoma dome.—The size and completeness of the Mascoma dome justify the emphasis given it here, and it may be taken as the type for the Mascoma quadrangle. It is located in the central part of the area, but extends north for a short distance into the Mt. Cube quadrangle. A central, domical, igneous core is surrounded by belts of metamorphic rocks, more or less concentrically arranged, in which the bedding and schistosity dip radially outward. The innermost belt consists predominantly of amphibolites, and constitutes the upper 600 feet of the Ammonoosuc volcanics. The next outer belt is the Clough formation, which is present mainly on the west side of the dome. Beyond the Clough is a wide belt of the Littleton schists. The foliation of the plutonic rocks near the contact also dips outward radially, and is parallel to the bedding and schistosity of the surrounding metamorphic rocks (see geological map). Well within the plutonic mass, however, the foliation pattern is much more complicated. This complex pattern is believed to have been produced from a simple concentric foliation which was later subjected to regional folding.

The bedding and schistosity of the metamorphic rocks dip north 20° to 25° at the north end of the dome, in the Mt. Cube quadrangle (Fig. 3). In the vicinity of North Peak in Hanover Township, the dip of the bedding and schistosity is 35° to 50° NW. This belt of metamorphic rocks has also been folded, and a small patch of Ammonoosuc volcanics has been brought up in the midst of the Clough formation, by an anticline, near the north end of Moose Mountain. Farther south the dips become steeper and steeper, so that west of Goss Neighborhood School, bedding and schistosity dip 75° to 85° W. Still farther south the bedding is vertical, and near the south end of Moose Mountain the bedding and schistosity have been overturned, to dip 80° to 85° E. It is probable that the narrow band of amphibolites continues southward under Mascoma Lake, but the resistant Clough formation is probably thin or absent. This may explain why the Mascoma and Knox Rivers were able to form the gap between Moose and Shaker Mountains.

The Clough and Ammonoosuc formations are readily followed from Lower Shaker Village to Butternut Pond. The bedding and schistosity of the rocks on the southwestern side of the dome have been crumpled into a series of folds which plunge at low angles to the south and southwest. The gentleness of this plunge explains the highly serrate contacts. Just west of Upper Shaker Village the folding is isoclinal, and the bedding and schistosity dip 70° east. Northwest of Smith Pond the folds are less

tightly compressed, and dips in bedding and schistosity are between 35° and 70°. Just west of Montcalm Hill the bedding and schistosity in the Clough is nearly horizontal, and the folds are broad and open. The schistosity of the rocks from Montcalm Hill to Butternut Pond dips about 40° west.

A normal fault, which extends from Enfield Village to the south end of the quadrangle, has repeated the belt of metamorphic rocks along the southwestern side of the dome, forming a band of Ammonoosuc volcanics along the eastern shore of Mascoma Lake and a band of Ammonoosuc volcanics and the Clough formation around Cole Pond. The metamorphic rocks around the southern end of the dome have been cut out by the intrusion of Bethlehem gneiss.

The eastern flank of the Mascoma dome, south of the normal fault in Canaan Township (Pl. 6), is composed of Ammonoosuc volcanics which originally dipped east at moderate angles. Regional folding, however, has thrown this belt of volcanics into a series of anticlines and synclines with low plunges. The schistosity in this belt may dip, either east or west, at angles between 20° and 70°. The great breadth of Ammonoosuc volcanics near Canaan Village is due to the presence of a subsidiary dome, bringing to the surface a small patch of the Mascoma group (Pl. 6). South of East Hill the Clough formation is exposed for a short distance on the east flank of the dome and dips 60° E.

The Ammonoosuc volcanics extending northwest from the normal fault in Canaan Township form an overturned syncline between the Mascoma and Smarts Mountain domes. At the southeastern end of this belt the fold is nearly isoclinal with dips of about 75° NE. At the northwestern end of the belt, the southwestern limb dips 40° NE, whereas the opposite limb is about vertical. The Ammonoosuc volcanics near North Canaan School form part of the downfolded roof of the dome. These volcanics are in an open syncline trending about N 25° W. The foliation in the surrounding granodiorite dips under the volcanics at an angle of 40° on the west, is horizontal on the northeast, but dips away from the volcanics at about 10° or 20° on the hill a mile southeast of North Canaan School. The fact that the foliation dips away from the volcanics at a low angle on the south, may be explained by cross folds which trend NE-SW.

Croydon dome.—The Croydon dome, in the southwestern part of the quadrangle, originally must have been a comparatively simple dome, but it is now modified by later folding and faulting. Near the margins of the intrusive the foliation in the Croydon group is parallel to the bedding and schistosity of the surrounding metamorphic rocks as well as to the contact, and it dips outward at angles of 25° to 45° (Pl. 6). Nearer the center of

the dome the foliation is weak and has been thrown into broad north-south folds.

The Clough formation on Croydon Mountain has been compressed into a series of north-south folds. Several of these folds extend northward for about two miles from the southern boundary of the quadrangle. Broad and open folds are characteristic of the eastern part of this belt, but farther westward, the folds are more tightly compressed, and near the contact with the Littleton formation they are almost isoclinal and overturned to the west. Just northeast of Stowell Hill is a small patch of Clough brought up in the midst of the Littleton formation, by an anticline. The metamorphic rocks around the northern end of the dome have been crumpled into a series of folds which plunge northward at moderate angles, giving somewhat sinuous contacts. The eastern part of the dome has been down-faulted by a normal fault, thus bringing the Bethlehem gneiss in contact with the Croydon group.

Smarts Mountain dome.—The Smarts Mountain dome, in the northeastern part of the Mascoma quadrangle, is asymmetrical. The axis of this highly elongated dome is located within a third of a mile of the southwestern contact of the Smarts Mountain group and the Ammonoosuc volcanics. Southwest of this axis the foliation of the Smarts Mountain group dips steeply to the southwest; northeast of the axis, the foliation dips 20° to 55° northeast. The bedding and schistosity in the metamorphic rocks along the southwestern flank of the domes is vertical in Dorchester Township, but it is slightly overturned farther south. The schistosity and bedding in the Ammonoosuc volcanics on Pollard Hill have been folded considerably, but in general, dip northeast at about 25°. The southern end of the Smarts Mountain dome is believed to have been displaced by an east-west fault.

Features in common to the domes.—There are eight important features common to all the domes. (a) The domes lie along the axis of the Bronson Hill anticline which trends north-northeast (Fig. 3). Its total length is at least 65 miles. (b) The long axes of the domes are at a small angle to the axis of the major anticline. (c) All the domes have a roof at about the same stratigraphic horizon, a few hundred feet below the base of the Clough formation. (d) The metamorphic rocks surrounding the igneous cores have a concentric schistosity which is, in general, parallel to the bedding. It is believed the bedding and schistosity originally dipped outward at low angles from the igneous cores, and that any marked variation from this relationship may be explained by later folding. (e) The foliation in the plutonic rocks near the contacts is parallel to the bedding and schistosity in the surrounding metamorphic rocks, but well within the domes, the foliation appears to be folded. (f) The north

ends of the domes are relatively simple, and bedding and schistosity dip northward at low angles of 20° to 35°. The structure of the south ends of the domes is not so well known, but it, too, is perhaps relatively simple. The eastern and western flanks, on the other hand, have been folded and crumpled to a considerable extent. (g) The metamorphic rocks between adjacent domes have been intensely crumpled. (h) The igneous rocks of the domes have a similar petrography.

Mechanics of intrusion.—Five hypotheses as to the mode of intrusion of the Oliverian magma series may be considered.

(1) The Oliverian rocks could not have been derived from the Ammonoosuc volcanics through palingenesis or anatexis, because these rocks have never been deeply buried. The total thickness of the known stratigraphic column above the roofs of these intrusives is 7000 feet, and it is doubtful whether the thickness of the sediments overlying this known stratigraphic column could have exceeded one or two miles.

(2) If the Oliverian magma were injected to form a series of phacoliths, it is conceivable that dome shaped bodies would form. Whereas such a mode of intrusion might account for a foliation within and parallel to the walls of the igneous masses, and would explain why the domes had a similar petrography and a common roof, it would not explain why the schistosity of the overlying and adjacent metamorphic rocks was parallel to the contacts of the intrusion and also parallel to the foliation of the igneous rocks.

(3) Objections, similar to those given above, may be raised to the hypothesis that the various domes are part of a single, large sill which was later folded and partly eroded.

(4) It is also difficult to understand how these domes could represent a series of small batholiths and stocks, arranged in a narrow zone over 65 miles in length, which formed their roofs everywhere at the same stratigraphic horizon. It should be noted that the stratigraphic position of the roofs does not vary more than a few hundred feet.

(5) Finding all other theories untenable, the author considers laccolithic intrusion to be the best mechanism. Not only does it explain the foliation of the intrusion and the concentric schistosity of the surrounding metamorphic rocks but it also explains why the domes should have roofs at the same stratigraphic horizon.

Origin of schistosity and foliation.—Had the intrusion of these igneous cores been rapid, the roofs, undoubtedly, would have ruptured through tension, thus providing an easy escape for the magma. Doming must have proceeded slowly, allowing the overlying rocks to deform plastically under the vertical load of thousands of feet of sediments. It is believed that the upward push of the magma, combined with the downward force

due to load, compressed and thinned the sediments. Elongation of the rock mass, which is essential to thinning, was permitted by an extension parallel to the bedding as the arches were being formed. Gilbert (1899, p. 81) calculates that the roof of the Lesser Holmes arch was elongated about two per cent when the laccolith formed. Brock (1934, p. 689) obtains the same value for one of the domes of the Shuswap terrain. In the Mascoma dome the elongation of the roof is calculated to have been at least 12 per cent of its original length. In describing the laccolith, Gilbert (1877, p. 82) says,

> "It was not *stretched* into the dome form; it was *compressed*. The efficient force did not act in the direction of the extension, but vertically. The sandstone was pushed, not pulled."

Following Brock (1934, p. 689), this type of deformation would require that, at any point on the laccolith, the strain ellipsoid be placed with its short axis normal to the bedding and its long axis parallel to the dip. The schistosity would develop parallel to the bedding. If a series of these ellipsoids were placed at intervals on the circumference of the dome, their long axis would radiate from some central point within the dome, and the intermediate axes would everywhere be parallel to the strike of the bedding. Thus a concentric schistosity would develop, and it would dip out radially from a central point within the dome. Although the perfectness of schistosity is, to a great extent, dependent upon the mineralogical composition of the rocks, this schistosity should be most pronounced in the lowest beds where thinning would be most intense. We would expect the schistosity to be less marked in the higher formations, and farther away horizontally from the igneous mass, as recrystallization is greatly enhanced by the heat and by solutions from the magma. It is then, a dynamo-contact metamorphism.

The foliation of the igneous rock is in part a flow structure, but it seems that this mechanism can be considered as important only in close contact with the walls. Perhaps still more important in the production of this foliation is the effect of doming. The upper parts of the laccoliths would start to crystallize early, and if crystallization were nearly complete before doming had ceased, the plates of biotite would become oriented in the crystal mesh in response to the same stress conditions as existed in the roof sediments.

Effect of regional folding and metamorphism.—After the foliation was produced, but perhaps before complete solidification of the magma, regional folding began. The linear distribution of the domes may have determined the position of the Bronson Hill anticline. During folding, the roofs of the domes were somewhat deformed. The development of a syncline, extending from Crystal Lake to past Halley School in Canaan

Township, separated a small part of the Mascoma dome, and formed the dome near Canaan Village. The Smarts Mountain dome appears to have been later pushed westward against the Mascoma dome, compressing the syncline on its western flank, and in places overturning the axial plane to the west.

The down-folding of the roof rocks of the Mascoma dome formed the syncline which brought down the Ammonoosuc volcanics near North Canaan School in the township of Canaan. This syncline trends northwest, about parallel to the syncline between the Mascoma and Smarts Mountain domes. The variation in direction and amount of dip of the foliation, particularly near the central part of the domes, suggests that the original, simple foliation pattern of the igneous rocks was folded during this period of regional compression (Pl. 6).

One of the best places to observe the effects of regional folding upon the roof rocks is along the southwestern flank of the Mascoma dome. Around Smith Pond the bedding and schistosity of much of the Clough are nearly flat, and the folds are broad and open. As one proceeds westward or northwestward from Smith Pond, the folds become more and more tightly compressed, until finally they are isoclinal, and the dome schistosity of the roof rocks appears parallel to the later regional schistosity. The igneous cores must have offered considerable resistance to this folding, and, undoubtedly, protected the overlapping rocks from considerable deformation. Thus we might expect decrease in intensity of folding of the roof toward the center of the dome.

The area of intense folding west and northwest of Smith Pond extends southward to Croydon dome, and is analogous to the intensely folded area between Owls Head and Smarts Mountain domes, in the Mt. Cube quadrangle. There is another similar area just north of the Owls Head dome in the Moosilauke quadrangle. These areas lie between domes (Fig. 3) and are probably the loci of most intense deformation, because they have not been protected by the buttressing effect of the igneous masses. In addition, any differential movement of two adjacent domes would help to intensify the degree of deformation in the intervening areas.

Minor structures.—There are inclusions of biotite gneiss within the Oliverian domes which are probably reworked fragments of the Ammonoosuc volcanics. In nearly all cases they are elongated parallel to the foliation of the igneous rock, and possess a schistosity parallel to their length.

As the magma was intruded into unmetamorphosed rocks, it is likely that many of the inclusions which sank into the liquid were more or less equidimensional. Small masses of femic volcanics might be quickly converted to a biotite rock, and, if doming continued after the surrounding

magma had almost completely crystallized, the inclusions would be drawn out parallel to the foliation of the igneous rock, simultaneously developing a schistosity parallel to their length. Those inclusions which were originally disk-shaped were rotated early, parallel to the foliation surfaces in the crystallizing magma. They may later have been sheared out into still thinner discs, at the same time developing a schistosity parallel to their length.

The apparent streaking out of biotite flakes, in the plane of foliation is another minor structure in the plutonic rocks of the domes. (1) In some places flakes of biotite appear to have slipped parallel to the basal pinacoid, giving rise to elongated crystals. (2) More commonly, however, one finds biotite flakes arranged in parallel lines in the plane of foliation. The linear features produced in both cases are believed to indicate the direction of movement in the plane of foliation. The streaking of biotite, as found in the plutonic rocks of the domes, has a plunge which is, in most cases, down the dip. Any marked departure from this arrangement may be due to regional folding. The linear features, then, seem favorable to the theory that the foliation was produced by doming of a crystallizing magma, the biotite being streaked out in the planes of shearing.

LEBANON DOME

General structure of dome.—The general structure of the Lebanon dome is similar to that of the other domes. It consists of a plutonic core of Lebanon granite and border gneiss, which is intrusive into the upper part of the Post Pond volcanics. Small dikes and sills of the border gneiss intrude the volcanics on Lords Hill and near the road between Hayes and Signal Hills. The concentric foliation of the border gneiss, which is equally well developed throughout the mass, dips radially outward from the center (Pl. 6). In the Post Pond volcanics, which extend from just north of Hanover Reservoirs to Lords Hill, the schistosity dips 35° to 75° northwest and is parallel to the foliation of the adjacent gneiss. At the northeastern end of the dome on Lords Hill, the bedding and an old schistosity dip 55° north. These, however, are cut by a latter schistosity which is vertical and strikes north-northeast. From Lords Hill southward, along this belt of Post Pond volcanics, to Lebanon village, the schistosity dips east at 45° to 90°.

Mechanics of intrusion and origin of schistosity and foliation.—Merritt (1921, p. 16) considered the Lebanon dome to be a laccolith. Although the writer accepts this interpretation for the domes of the Bronson Hill anticline, he believes the Lebanon intrusive is more likely a stock which has domed its roof. Either the stock or laccolithic hypothesis will explain most of the features of the dome, but from his study of the eastern half of the dome, the writer is inclined to favor the former.

The composite character of the igneous core is, perhaps, more in favor of the stock hypothesis. The border gneiss was first intruded as a stock, and perhaps before it had completely crystallized, the upward push of the magma domed the overlying beds. As in the other domes, this doming mechanism could produce a foliation in the igneous rock, which was concentric and parallel to the schistosity formed contemporaneously in the surrounding Post Pond volcanics. After the border gneiss had solidified, the Lebanon granite was intruded, as shown by the abundance of inclusions of the border gneiss in the granite.

Effect of regional folding and metamorphism.—The fracturing and granulation of the microcline phenocrysts in the granite core was probably brought about by regional folding which followed intrusion. In general, this regional deformation was incapable of producing a new foliation in the igneous rock, but it was sufficiently intense to shatter the phenocrysts on microcline (Pl. 3, fig. 3). The effects of regional folding and metamorphism upon the rocks surrounding the igneous core are much more pronounced. Two distinct schistosities have been mentioned in the Post Pond volcanics on Lords Hill. The older schistosity which dips 55° north, parallel to the bedding, is believed to have been formed during the intrusion of the border gneiss, and it is equivalent to the concentric schistosity of the other domes. The later schistosity which is vertical and strikes north-northeast is considered as the regional schistosity superimposed upon the earlier dome schistosity. The fact that this old foliation is at right angles to the regional schistosity explains why the former still persists. Throughout the rest of the metamorphic rocks only one schistosity is recognized in any one outcrop. On the sides of this elongated dome, this is to be expected, as the strikes of the two foliations would be approximately the same, and the difference in dip might be small. Thus it would be difficult to recognize both features. Moreover, the older schistosity may have been folded isoclinally, and thus made parallel to the newer regional schistosity.

SALMON HOLE BROOK SYNCLINE

The area bounded on the west or northwest by the Ammonoosuc thrust, and on the east or southeast by the Northey Hill thrust is known as the Salmon Hole Brook syncline (Fig. 3). This major syncline was named and mapped by Billings (1935, p. 31) in the Littleton and Moosilauke quadrangles. Later field work, by Billings in the Woodsville quadrangle and by Hadley in the Mt. Cube quadrangle, showed that this same fold continued southwestward into the Mascoma quadrangle. Much of the eastern limb of this fold has been cut out, in the Mascoma quadrangle, by the Northey Hill thrust so that the axis of the syncline lies very close to the fault.

The Hardy Hill quartzite member of the Orfordville formation is one of the keys to the detailed structure of the Salmon Hole Brook syncline in the Mascoma quadrangle. Ten days of field work were devoted to a study of the quartzite by pace-and-compass methods, and detailed maps were then prepared on a scale of 800 feet to the inch. Directly beneath the quartzite is a thin bed of volcanics; in places, where the quartzite is absent, the volcanics serve as a good horizon marker. Although the most northerly outcrop of the quartzite in the Mascoma quadrangle is half a mile east of Hanover Center, the horizon itself may be traced for a mile farther north, by means of the bed of volcanics. From this point southward, the Hardy Hill quartzite may be traced almost continuously to East Plainfield.

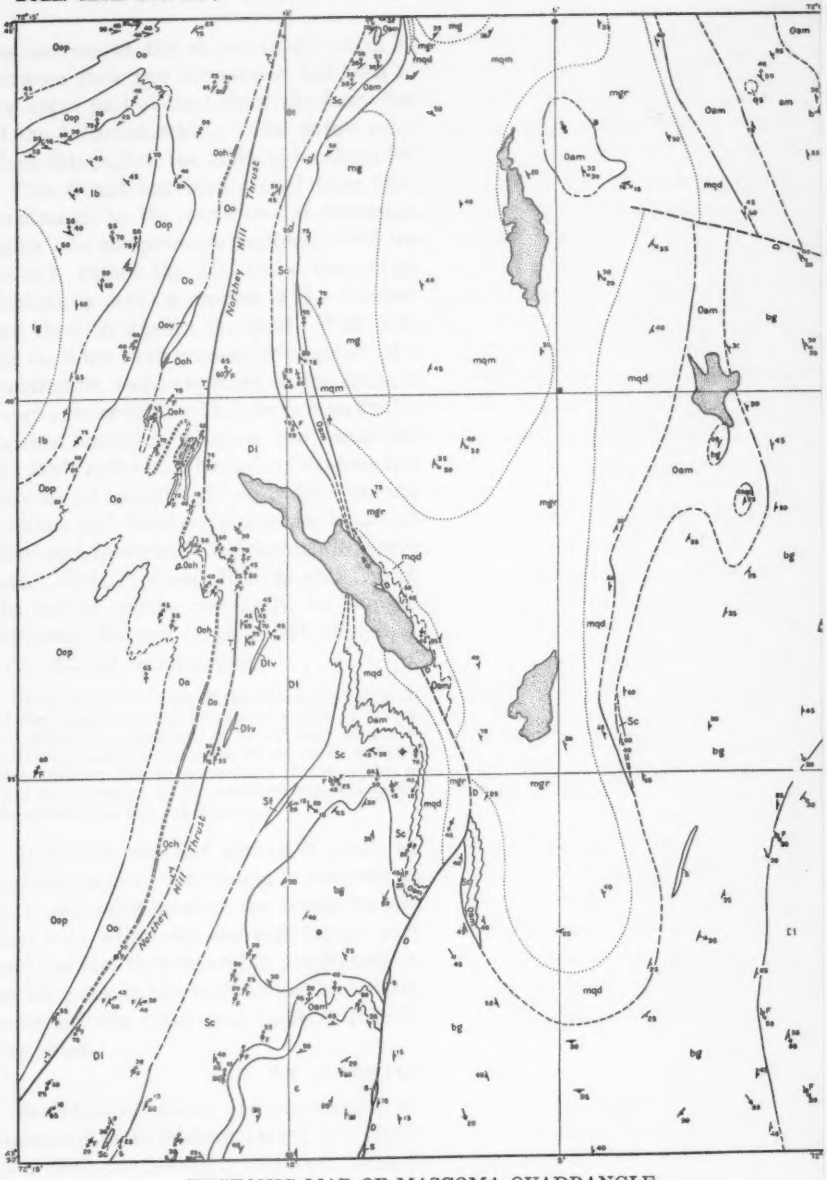
Detailed mapping shows that the quartzite has an intricate, zig-zag pattern; the belt as a whole trends about S 10° W, whereas the strike of the bedding at any locality is about S 25° W. This pattern suggests intense folding; numerous observations on single outcrops corroborate this. On an average the individual folds plunge 60° NE. Thus the Hardy Hill quartzite is on the west limb of a syncline plunging northeast.

Another good horizon marker in the Salmon Hole Brook syncline is the top of the Post Pond volcanics. From north of Huntington Hill in Hanover the horizon may be traced southwest, along the northwestern limb of a syncline, for an unknown distance into the Hanover quadrangle. It may be traced back again, on the southeastern limb of the syncline, as far as Lords Hill. From there it extends southwest to Lebanon Village. Reconnaissance work in the Hanover quadrangle shows that this contact continues for about four miles southwest of Lebanon, along the northwest limb of another syncline, and returns again on the southeast limb. For about three miles southeast of Lebanon Village the contact is highly folded; but from here southwestward, it is comparatively straight.

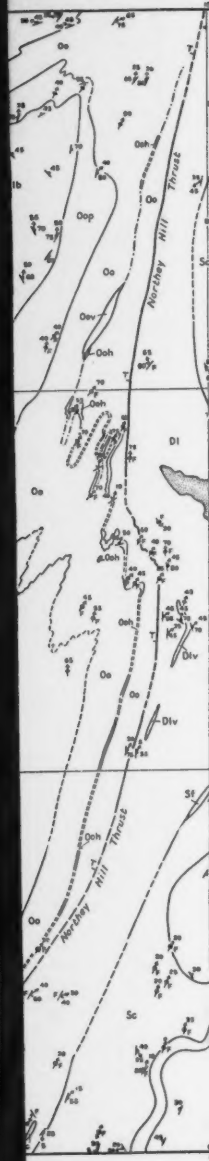
This contact has been folded more or less harmonically with the Hardy Hill quartzite as can be seen from the geological map. Furthermore, the fold pattern of both this contact and the quartzite indicates that the rocks in the western part of the quadrangle form the western limb of a syncline (Salmon Hole Brook syncline); the eastern limb is cut out by the Northey Hill thrust.

NORTHEY HILL THRUST

The Northey Hill thrust extends southward from North Neighborhood School in Hanover Township, to Arvin School, Mt. Tug, Potato Hill School, and Methodist Hill. From here it extends southwest to Cornish Township. A pace-and-compass traverse from near Mt. Tug to the highway south of Potato Hill School shows the contact between the Orfordville and Littleton formations to have a zig-zag pattern similar to that already described for the Hardy Hill quartzite. This indicates that



TECTONIC MAP OF MASCOMA QUADRANGLE



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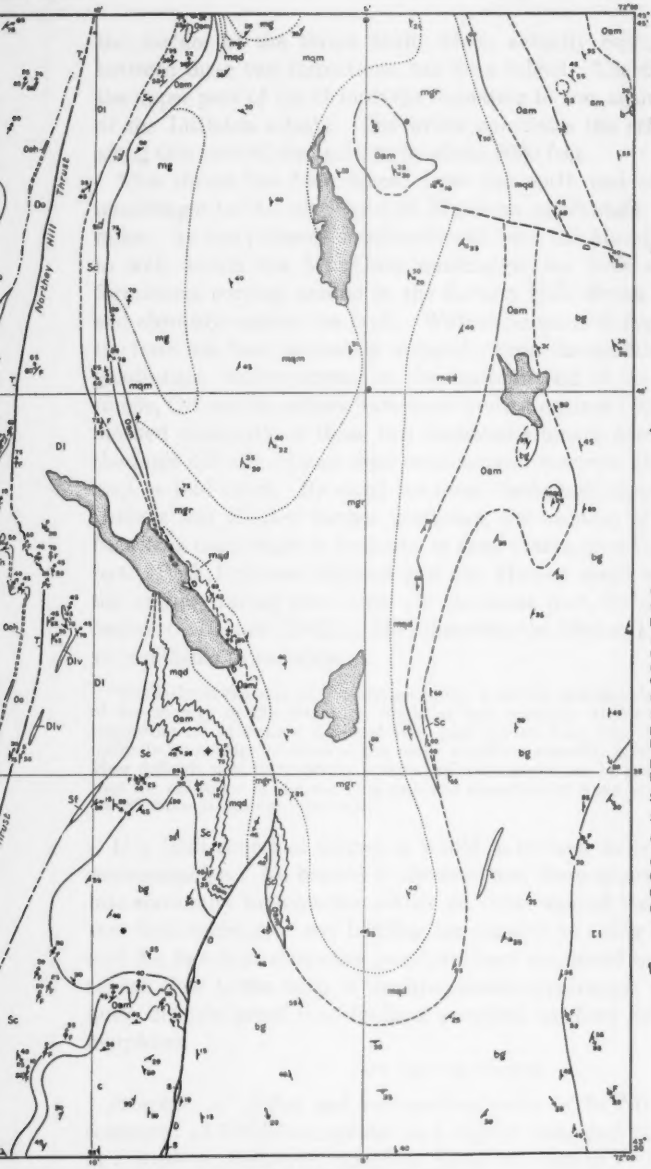

LEGEND

STRUCTURAL SYMBOLS

- Strike and dip of bedding
- Horizontal bedding
- Bedding and linear element
- Strike and dip of foliation or schistosity.
- Vertical foliation or schistosity.
- Horizontal foliation or schistosity.
- Foliation or schistosity and linear element.
- Foliation or schistosity with linear element directly down dip.
- Vertical foliation or schistosity and linear element.
- Horizontal foliation or schistosity with horizontal linear element.
- Strike and dip of axial plane of fold with direction and value of plunge of fold.
- Direction and value of plunge of fold with vertical axial plane.
- Fold with horizontal axis and vertical axial plane.
- Linear element alone.

FORMATIONS

qs	Quartz syenite	
vb	Volcanic breccia	
bg	Bethlehem gneiss	
mg	Granite	Mascoma group
mqm	Quartz monzonite	Mascoma group
mgr	Granodiorite	Mascoma group
mqd	Quartz diorite	Mascoma group
sm	Smarts Mountain group	
c	Croydon group	
lg	Granite	Lebanon group
lb	Border gneiss	Lebanon group
Dl	Mica schist, etc.	Littleton formation
Dlv	Volcanics	Littleton formation
Sf	Fitch formation	
Sc	Clough formation	
Oam	Ammonoosuc volcanics	
Oo	Black schist, etc.	Orfordville formation
Ooh	Hardy Hill quartzite	Orfordville formation
Oov	Volcanics	Orfordville formation
Oop	Post Pond volcanics	Orfordville formation
s	Silicified fault zone	

Scale in Miles

0 1 2 3

TECTONIC MAP OF MASCOMA QUADRANGLE

the surface of the thrust fault, which actually represents the contact between these two formations, has been folded. The thrust has brought the upper part of the Orfordville formation to rest against the upper part of the Littleton schists. The writer calculates the stratigraphic throw, along this part of the fault, to be about 9000 feet.

This thrust has been traced from the north end of the Moosilauke quadrangle to the south end of Mascoma quadrangle, a distance of 58 miles. As one proceeds southwestward from the Moosilauke quadrangle, to well within the Mt. Cube quadrangle, he finds successively older formations curving around in the Salmon Hole Brook syncline, only to end abruptly against the fault. With different rock types on either side, the fault has been accurately mapped. From the middle of the Mt. Cube quadrangle, southwestward to the southern end of the Mascoma quadrangle, Orfordville schists have been faulted against Littleton schists; the marked similarity of these two formations makes accurate mapping of the fault difficult. Upon close examination, however, the two formations may be told apart. By using the same distinguishing criteria as used by Billings and Hadley farther northeast, the location of the fault in the Mascoma quadrangle is accurate, in most places, to within a few hundred feet. Both Professor Billings and Dr. Hadley spent several days with the author tracing this fault, for the most part, by pace-and-compass methods. Barrow (1912, p. 284) describes the Moine thrust as also being very difficult to recognize.

> "Similarly in the case of the Moine-thrust; a skilled stratigraphist, knowing nothing of the country or the literature, would at first cross the Moine-thrust without even suspecting its existence; it would take him a very long time to locate it, and an intimate knowledge of most of the rocks would be essential before he could trace it. How difficult it is to recognize a thrust of this nature can be gathered from the fact that the existence of the southern one was disputed for some years, indeed in Arran its existence is not yet admitted."

If a fault zone had formed it would have been destroyed by regional metamorphism. No breccia is observed and there appears to be an absolute continuity between the schists on either side of the fault. The fact that both schistosity and bedding are parallel on either side of the fault, and the fact that staurolite porphyroblasts are found undisturbed in the schists close to the fault in the Moosilauke quadrangle (1937, p. 531), is quite definite proof that faulting preceded isoclinal folding and metamorphism.

MT. CLOUGH PLUTON

Structure of pluton and surrounding rocks.—The Mt. Clough pluton, composed of Bethlehem gneiss, is a highly elongated intrusive, trending in a north-northeasterly direction, along the eastern limb of the Bronson Hill anticline. It is at least 65 miles long and extends from the Franconia quadrangle to the Sunapee quadrangle (Fig. 3). It may be seen from the

geological map of the Mascoma quadrangle (Pl. 6) that there is a marked tendency for the foliation to be parallel to the contacts of the intrusion, and also parallel to the schistosity of the adjacent metamorphic rocks.

Northeast of Crystal Lake in Canaan Township, the foliation dips from 30° to 50° NE, but farther south, around Canaan Village, the dip is 40° to 60° E. A mile east of Halley School in Canaan Township, the foliation dips 25° SE. The small mass of Bethlehem gneiss which forms the Pinnacle in Canaan Township, however, has a foliation which dips at 35° W. From the road between Halley School and the Height of Land School in Grafton Township southward, almost to the Grafton county line, the foliation in the gneiss dips uniformly to the east, at angles of 35° or 40°. Just south of East Hill, where the Clough and Ammonoosuc volcanics dip 60° to 70° E, the foliation in the gneiss is also 60° to 70° E.

This structural conformability is brought out, perhaps most strikingly, around the southern end of the Mascoma dome. In the vicinity of Carter Brook in Springfield Township the foliation of the Bethlehem dips 20° to 35° E and SE. Near Washburn Corner it dips 30° to 50° S. From here northward to Cole Pond in Enfield Township it dips 45° to 60° W. West of the large normal fault which passes through Butternut Pond in Grantham Township there is a large oval-shaped area of Bethlehem gneiss. In general the foliation dips in toward the center of the oval at angles from 30° to 45°, although locally higher dips are observed. In the central part of this area the foliation is flat. Southwest of Eastman Pond in Grantham Township, the dip of the foliation is to the east and decreases from 40°, south of the "M" in "GRANTHAM," to about 10° at the fault farther west.

Along the eastern contact with the high-grade schists the foliation dips 45° east and is about parallel to the schistosity of the metamorphic rocks.

Mode of intrusion and origin of foliation.—The foliation of the Bethlehem gneiss is believed to be a primary flow structure. This is shown in part by the slab-like inclusions which are oriented parallel to the foliation. Originally some of these may have been disk-shaped and rotated into parallelism with the foliation. Others may have been sheared out into elongated masses, parallel with the flow structure. Even more compelling, however, are the shear zones in the gneiss filled with pegmatitic material. The foliation shows drag due to movement along these shear zones; the shearing must have occurred after the foliation was produced, but while some residual liquid was still left. The marked parallelism between the foliation of the gneiss and the strike of its contacts rules out the possibility that such a foliation could have been produced by horizontal compressive stresses. From these three lines of evidence one must conclude that the Bethlehem gneiss is a primary gneiss.

The flow structure can not be due solely to drag against the walls, for it is almost uniformly developed throughout the body. The foliation could be produced, however, if we assume a forceful intrusion of a partly crystalline magma so that flow layers would develop between crystal grains and the biotite become oriented into these flow layers. On this assumption we could explain the granoblastic texture of the gneiss as due to the mutual interference and granulation of crystals in a semi-solid magma.

The Bethlehem gneiss is believed to form a huge, sheet-like mass which, in the Mascoma quadrangle, forced its way up over the Mascoma dome and down the western side (cross-section C–C′, Pl. 6). There are four main lines of evidence which favor such an interpretation.

(1) The shape and structural position of the body as brought out by geological mapping. The body is an intrusive mass elongated parallel to the regional structure (Fig. 3). The Littleton formation is everywhere present on the eastern flank, whereas the Clough or Ammonoosuc usually form the western contact. Cross-cutting relations are insignificant when compared with the magnitude of the intrusive. This body, therefore, occupies essentially the same stratigraphic position throughout its extent.

(2) The pegmatites from the Bethlehem gneiss are confined almost wholly to the schists along the eastern contact. If the Bethlehem gneiss in the Mascoma quadrangle forms a thick sheet, the eastern contact of which dips 45° to the east, then we would expect to find the pegmatites most abundant on the eastern side, as it would be here, in the hanging wall of the intrusive sheet, that the escaping fluids from the crystallizing magma would concentrate. Conversely, we would expect to find few pegmatites along the western contact in the footwall. These expectations are borne out by field facts. A moderately dipping contact would also explain the extremely broad band of pegmatites in the schists, and why the outermost members of this belt appear to be so far removed from the igneous source.

(3) It is believed that the parallelism of the foliation in the gneiss and the bedding and schistosity of the metamorphic rocks indicate a low angle of dip for the contacts of the intrusive. The small patch of westerly dipping gneiss which holds up the Pinnacle in Canaan Township is probably a small outlier of the main intrusion. The concentric structure around the southern end of the Mascoma dome would indicate that the Bethlehem originally wrapped up over and down the western side of that dome. This sheet of gneiss extended as far west as Leavitt and Miller Ponds in Grantham Township. The nearly isolated mass of Bethlehem west of the fault in Grantham Township is interpreted as lying on top of the Clough formation, in a basin-like structure between the two domes. The inwardly dipping foliation, around the outer part of the mass, and

the horizontal structure in the center is in agreement with this interpretation. The dropping-down of the eastern block along the fault in Grantham Township has prevented erosion from removing the Bethlehem and underlying Clough and Ammonoosuc volcanics from the eastern half of the Croydon dome. The gneiss must have originally extended up over the Croydon dome, and must have been continuous with the basin-like mass around Leavitt Pond. This would explain why the foliation in the gneiss is nearly flat southwest of Eastman Pond; it must represent a flat-lying foliation in the Bethlehem which is wrapping up over the Croydon dome. In addition to the parallelism of structure in the Bethlehem and in the high-grade Littleton formation, the evidence of the pegmatites is in favor of a low angle dip for the eastern contact of the intrusive.

(4) It will be noticed from Figure 3 that the Bethlehem wraps around the southern end of the Owls Head dome as well as the Mascoma dome. It will also be noticed that the magma was able to intrude farthest to the west where there was a low divide in the Bronson Hill anticline. These two facts suggest that the magma was intruded along a definite horizon, and therefore has the characteristics of a concordant sheet.

Position of intrusion in tectonic sequence.—The high-grade Littleton east of the Bethlehem gneiss commonly exhibits a moderately or intensely folded schistosity. The foliation of the gneiss, however, is only locally wavy and is never observed to be even moderately folded. The fact that the foliation of the gneiss has been scarcely disturbed, even in the vicinity of its contact with the high-grade Littleton schists, the schistosity of which is conspicuously folded, would favor the belief that the Bethlehem was intruded after the major part of the folding but, perhaps, while regional stresses were still weakly active. The writer believes that the evidence in the Mascoma quadrangle favors placing the date of this intrusive only slightly later than that determined by Billings (1937, p. 537) in the Littleton and Moosilauke quadrangles. As has already been shown in the discussion of the New Hampshire magma series, the geological age of the Bethlehem gneiss is probably late Devonian.

NORMAL FAULTS

Extending southward from Mascoma Lake, for an unknown distance into the Sunapee quadrangle, is a normal fault, along which the eastern block has been dropped down. Along the southern part of the fault the Bethlehem gneiss comes in direct contact with the gneiss of the Croydon dome. Near North Grantham the belt of Clough and Ammonoosuc volcanics, encircling the Croydon intrusive, ends abruptly against the Bethlehem gneiss. The eastern part of the Croydon dome has been down-faulted. At Butternut Pond another belt of Clough and Am-

monoosuc volcanics ends abruptly against the Bethlehem gneiss, but it is repeated farther east, near Cole Pond. Between these belts the Bethlehem gneiss comes in direct contact with the gneiss of the Mascoma dome. A structural break, therefore, is obvious; see section C–C′, Plate 6. The repetition of the belt of Ammonoosuc volcanics along the northeastern shore of Mascoma Lake is further evidence, confirming the existence of a normal fault farther south. If the roof of the Mascoma dome were projected northward from around Smith Pond, it would pass several thousand feet above Mascoma Lake. It seems logical, therefore, to explain this belt of volcanics by down-faulting of the roof.

Along much of its course the fault may be accurately located by the aid of silicified zones. Where the fault leaves the southern part of the quadrangle there is a large silicified zone which trends N 20° E, has a maximum width of 200 feet, and is several hundred yards long. On the east side it forms a steep cliff about 50 feet high. The dip of the zone appears to be 70° E. Brecciated Croydon gneiss is cemented by quartz, in the western part of the zones, but brecciation of the Bethlehem gneiss was not observed. Where the fault crosses the hill, a mile farther north, there is a smaller silicified zone. Here the brecciated Croydon gneiss is more abundant, but the Bethlehem seems scarcely disturbed. The individual fragments of Croydon gneiss are brittle, having been highly silicified. They also have been leached of biotite. The dip of this zone is very steep, judging from its straight course across the hill. Northwest of Anderson Pond in Grantham Township, is still a third silicified zone about 30 feet wide. This can be traced, somewhat interruptedly, for a distance of over a thousand feet. On the southeast side of the zone is a fault plane which strikes N 30° E and dips 65° SE. On this surface there are fault grooves which plunge S 30° E at 60°. The Bethlehem gneiss is exposed immediately to the east and west. The Mascoma gneiss northeast of Butternut Pond in Grantham Township, has much the same appearance as the Croydon gneiss already described along the fault. It is brittle, highly silicified, and contains little biotite. The gneissic structure is vague, and the whole mass appears to have been highly shattered. Near the lake-shore, east of the "O" in "MASCOMA LAKE," is a small silicified zone which may have formed along this fault.

The throw of the fault has been calculated at three different points; near Mascoma Lake, south of Prospect Hill in Enfield, and near the southern boundary of the map. All three values obtained were approximately 4000 feet.

The east-west fault in Canaan Township is hypothetical. No such fault has been observed, but it best explains the adjacent structures in both the Mascoma and Cardigan quadrangles (Fowler-Lunn and Kingsley, 1937, p. 1374). The silicified zone which holds up Banks Pinnacle in

Grafton Township may have been formed along a fault in the Bethlehem gneiss. Judging from the steep face exposed on the southeast side of the pinnacle, this zone probably dips at a steep angle to the southeast.

ORIGIN OF OLIVERIAN MAGMA SERIES

GENERAL STATEMENT

The author presents the following theory to explain the diversity of igneous rocks in the Oliverian domes of the Bronson Hill anticline. No consideration is given to the Lebanon dome. The theory is based primarily upon observations made in the field and laboratory, and deals only with the changes which took place in the domes, after the magma was intruded. More detailed consideration will be given to the Mascoma group, as this group has the greatest variety of rock types.

The igneous rocks of the Oliverian series range in composition from quartz diorite to granite, there being all gradational types. In the Croydon dome quartz diorite comprises most of the igneous core, save for a small amount of granodiorite and perhaps a little quartz monzonite, near the center of the body. The geological map shows the distribution of the various types in the Mascoma dome. The relative abundance, as seen at the surface, is as follows: granodiorite, quartz monzonite, quartz diorite, and granite. There is a slightly eccentric arrangement of the rock types, with the granite located near the western flank of the dome. In the Smarts Mountain dome in the Mascoma quadrangle, quartz diorite is more abundant than granodiorite; but in the Mt. Cube quadrangle Hadley has found the granodiorite to be the predominating type. The writer estimates the relative abundance of these rock types at the surface of all the domes to be as follows, in decreasing order: granodiorite, quartz diorite, quartz monzonite, and granite.

CONTACT EFFECTS OF MAGMA

In the Mascoma dome there is a zone, a few hundred feet wide, which is transitional between the intrusive rock and the surrounding Ammonoosuc volcanics. This transitional rock is a composite gneiss, produced by the intimate association of the Oliverian magma and the Ammonoosuc volcanics, which were converted to biotite gneiss. The magma was injected in thin, sill-like masses between the bedding of the volcanics. These small sills are so abundant that the intersill rock is now represented by a series of thin, sheet-like inclusions oriented parallel to the gneissic structure. The thickness of the sills and intersill rock varies from a fraction of an inch to several feet. The contacts of the sills are not sharp against the inclusions, but the light-colored grades into the darker colored inclusions. The bulk composition of the feldspars of several specimens of these transitional rock types is shown in Figure 5 (within the

circle). These rocks contain andesine, whereas the strictly intrusive rocks seldom contain plagioclase more calcic than oligoclase.

GENERAL THEORY

The author's theory for the origin of the Oliverian magma series is composite, involving the processes of assimilation, pure melting, fractional crystallization, and replacement. It is assumed that a granodiorite magma was intruded to form the laccoliths, and non-uniform conditions of crystallization caused a slight heterogeneity. Assimilation of small amounts of Ammonoosuc volcanics would also help to explain some of this heterogeneity. Thus far, the theory explains all the plutonic rocks of the Smarts Mountain and Croydon domes; but to account for the more granitic rocks of the Mascoma dome, the process of replacement is here accepted.

After the laccolith had crystallized, and perhaps while it was still being deformed by regional stresses, solutions rich in potash rose from the solidifying magma reservoir below. Controlled somewhat by the gneissic structure in the laccolith, they were directed toward the western flank of the Mascoma dome, where they partially replaced the rock with potash feldspar. By this process, hereinafter referred to as replacement, the quartz diorites and granodiorites in the western half of the dome are believed to have been converted into rocks with compositions equivalent to quartz monzonites and granites. This process may not be considered one of gaseous transfer, as emphasized by Fenner (1926, p. 743), because it is not a process of differentiation. It is hydrothermal replacement by microcline, of a completely or nearly completely crystallized rock.

EVIDENCE OF REPLACEMENT

The several lines of evidence which favor the hypothesis of replacement are:

(1) The rock types are gradational and not cross-cutting. Thus, any theory involving a succession of intrusions from a chemically changing magma-source is incapable of explaining the rock types of the Mascoma dome.

(2) Near the contact along Moose Mountain it is common to find fine-grained igneous rocks with the characteristic appearance of quartz diorites, but with enough large crystals of microcline to give the bulk composition of a quartz monzonite or granite. In thin section the groundmass of these rocks looks like the typical quartz diorite, and in many specimens the plagioclase is An_{25} or An_{30}. These rocks appear to be the original quartz diorite replaced by metacrysts of microcline, so as to change the composition to a more granitic type. This same phenomenon is observed, somewhat less frequently, near the center of the dome.

(3) The presence of a band of microcline-rich quartzite on Moose Mountain, where the Clough formation comes in contact with the granite, is another line of evidence in favor of the replacement theory. The effects of replacement by microcline extend out for about 100 feet into the quartzite, and replacement is so complete that, in the field, it is difficult to find the true contact between the two rocks. In thin section, however, the quartzite may be distinguished by the absence of plagioclase and presence of muscovite. The microcline occurs in metacrysts of about the same size and shape as those in igneous rocks.

(4) The granoblastic texture of the dome rocks, the granulation of the large quartz phenocrysts, and the folding of the gneissic structure of the dome all indicate that the Oliverian domes suffered considerable shearing and deformation subsequent to crystallization. Even within the same thin section, highly granulated quartz phenocrysts are observed, but the large crystals of microcline are not granulated, nor even fractured. This strongly suggests that the large crystals of microcline are not phenocrysts, but are metacrysts, and were introduced after most of the deformation had ceased. It is probable that much of the microcline in the groundmass of these rocks is feldspar which was introduced while the rock was being sheared. Any large metacrysts which could have been formed would immediately have been granulated, and the microcline would have taken its place in the mosaic, along with the quartz and plagioclase.

(5) If these crystals of microcline were intratelluric phenocrysts, the magma must have been extremely rich in potash feldspar. It must have been so rich in potash feldspar that microcline was the first mineral to crystallize. The composition of such a magma would lie within the orthoclase field of the orthoclase-anorthite-albite diagram. We would expect, then, to find granite or quartz monzonite the predominating rock type derived from such a magma, and not a potash-poor granodiorite. Since the bulk composition of the plagioclase, in the Mascoma dome, is oligoclase (An_{23}), the microcline-oligoclase ratio would have to be at least 2:1 in order to lie within the orthoclase field of the ternary diagram given by Bowen (1928, p. 231). This ratio is represented by point X in Figure 4. It is nearly as high as that for the most potash-rich granites of the Mascoma dome. In no case is the microcline-oligoclase ratio of the dome known to exceed 5:2; and, furthermore, the ratio for the dome as a whole is estimated to be only 1:3. Starting at some point such as Y, orthoclase will crystallize until the boundary curve AB is reached. At this point, both orthoclase and plagioclase will crystallize, and the composition of the liquid will move along the boundary curve to A. At A the last drop of liquid will be gone. Every rock formed from such a liquid, however, will have a potash feldspar-plagioclase ratio greater than

3:2, and it will be impossible, on this theory, to explain the abundance of granodiorite and quartz diorite in the Mascoma dome.

(6) The uniformity of composition of the plagioclase in these rocks is also strongly in favor of replacement. In any particular magma series

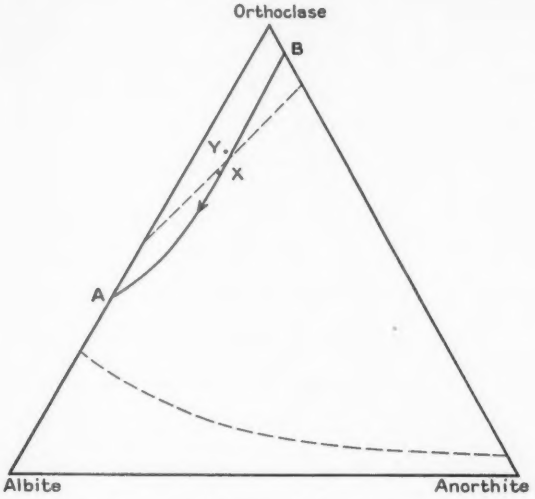

FIGURE 4.—*Ternary diagram of the system, orthoclase-anorthite-albite (after Bowen)*

of calc-alkaline rocks, the more granitic types contain the more sodic plagioclase as is well known. This is not the case, however, with the Oliverian magma series. The bulk composition of the feldspar, as obtained from the estimated modes of 49 thin sections of the Oliverian intrusives, is plotted in Figure 5. Of these, 39 are from the Mascoma dome, 5 from the Croydon dome, and 5 from the Smarts Mountain dome. These points lie near a straight line which passes through the potash-feldspar corner of the field. The plagioclase, therefore, has essentially the same composition in all the rock types. This may be explained by assuming partial, localized replacement of a slightly heterogeneous rock by microcline. Thereby, quartz diorites and granodiorites are changed to rocks with the composition of granite and quartz monzonite.

(7) In Figure 6 is plotted the mineral composition, as obtained from the estimated modes, of the same 39 specimens from the Mascoma dome as in Figure 5. As biotite is about equally abundant in all the rock types, it has been excluded from the plot. This plot shows a definite decrease in the amount of quartz, as well as plagioclase, as the amount of microcline

increases. The granites, therefore, have less quartz than the quartz diorites. The above relationship may be interpreted as evidence in favor of the hypothesis of replacement; but, at the same time, it may not be taken as conclusive proof thereof.

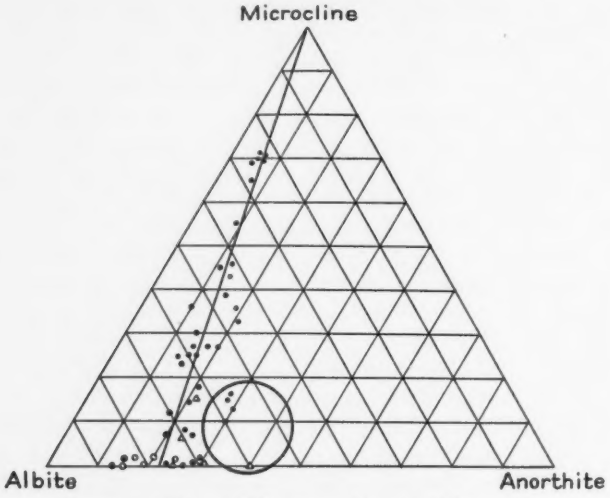

FIGURE 5.—*Plot of bulk composition of feldspars from estimated modes of Oliverian intrusives*

Dot = Mascoma group, triangle = Smarts Mountain group, circle = Croydon group.

The compositions within the circle are obtained from the transitional rocks formed by reaction between Ammonoosuc volcanics and the original magma.

METAMORPHISM

GENERAL STATEMENT

Many of the major problems, encountered in a detailed study of the metamorphism in western New Hampshire, have been considered by Billings (1937) for the Littleton-Moosilauke area. In the ensuing discussion, therefore, attention will be focused chiefly on new data or interpretation.

Only the middle and high-grade zones of metamorphism are present in the Mascoma quadrangle; the rocks belonging to the middle-grade zone lie west of the Bethlehem gneiss, and those of the high-grade zone lie east of the Bethlehem. In the middle-grade zone there is considerable variation in the intensity of metamorphism. According to Barrow's (1912) classification, these rocks would range in degree of metamorphism from the biotite

zone to the staurolite zone. Barrow's position of the kyanite zone (between the staurolite and sillimanite zones) can not be considered correct, at least for the Mascoma quadrangle. The author believes that kyanite will form in lower zones of metamorphism than was recognized by Barrow.

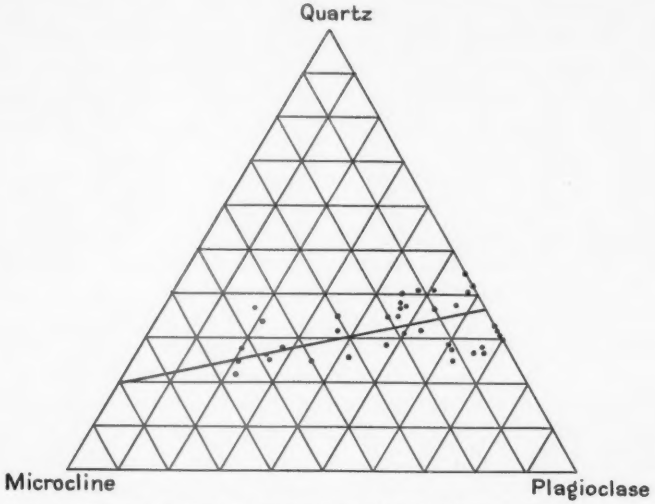

FIGURE 6.—*Plot of estimated modes of Mascoma group, biotite neglected*

MINERALOGICAL DATA

Amphibole.—Amphibole is present, in small amounts at least, in the metamorphic rocks throughout the area, and it remains stable up to the highest grades of metamorphism. Blue-green hornblende is the predominating type, and is most abundant in the femic rocks of the Ammonoosuc volcanics. The optics of several of these hornblendes are given in Table 3. There is a close resemblance between these hornblendes and an analyzed hornblende from the Littleton-Moosilauke area (see Lithology and Petrography of the Ammonoosuc Volcanics).

Chlorite.—Chlorite is apparently a stable mineral in the middle-grade zone, although most of it (penninite and ripidolite) has developed from other minerals through the process of retrograde metamorphism. Rocks of the Post Pond member, particularly those north of Gleason Cemetery in Plainfield Township, contain large quantities of chlorite and, in some cases, porphyroblasts of biotite. Muscovite is absent so these rocks must be low in potash. A little of the original chlorite combined with what

muscovite was present to form the porphyroblasts of biotite, but the rest recrystallized into slightly larger and clearer-cut flakes. This chlorite, therefore, is stable in the biotite zone because there is no potash available to form biotite. In the black, garnet-mica schists of the Orfordville formation, probably of a little higher grade of metamorphism than those near Gleason Cemetery, part of the chlorite has been converted to garnet. Muscovite was absent so biotite could not form. This chlorite (thuringite) evidently is not stable in the upper part of the middle-grade zone. If biotite has not formed because of a lack of potash, chlorite will be transformed into garnet. Evidence in support of this statement will be given in the discussion on garnet.

Much of the chlorite (probably prochlorite) appears to be a late mineral, since it cuts across the schistosity, as can be seen in several thin sections of the Littleton and Orfordville schists. It occurs in sharply formed porphyroblasts and cuts flakes of biotite and muscovite. These chlorite porphyroblasts do not represent altered biotite crystals, because the rest of the biotite in the rock is fresh. It is apparently a higher temperature form of chlorite, and has developed like the porphyroblasts of any other mineral, or it may be a low-temperature chlorite which developed in large crystals during retrograde metamorphism.

The occurrence of chlorite (amesite) with muscovite in the kyanite schists in Plainfield Township would suggest that the reaction between muscovite and amesite to form phlogopite takes place at a higher temperature than does the reaction between muscovite and other chlorites to form biotite. Therefore, in the presence of muscovite, the magnesium-aluminum chlorite is more stable in higher zones of metamorphism than are the more common chlorites. Although these rocks contain kyanite, they do not represent the same grade of metamorphism as do the kyanite schists first described by Barrow (1912, p. 275).

Garnet.—Crystals of almandite occur up to an inch across and may be irregular or in well-formed dodecahedrons. Some are homogeneous, whereas others are inclusion-filled or highly skeletal. Inclusions consist mainly of quartz, feldspar, magnetite, and carbonaceous bands, and may be elongated parallel to the elongation of the garnet and the schistosity of the rock. Garnet seems to be a late mineral. It replaces bands of biotite, muscovite, and chlorite and may even replace well developed porphyroblasts of biotite. It is commonly seen replacing bands of biotite and muscovite in the high-grade zone. It occurs in staurolite crystals, but whether as an inclusion or as a replacing crystal is uncertain.

Masses of garnet a centimeter across appear to be homogeneous crystals in some of the Littleton and Orfordville schists, but microscopic study shows they are skeleton crystals enclosing quartz (see Pl. 4, fig. 2). The

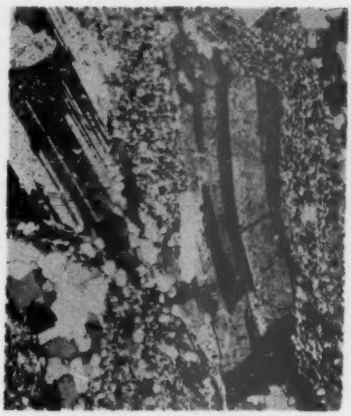

FIGURE 1. BENT CRYSTAL (INTRA-TELLURIC) OF OLIGOCLASE
In quartz-oligoclase-microcline gneiss (metamorphosed volcanic tuff) from Post Pond volcanic member. Nicols crossed (× 14).

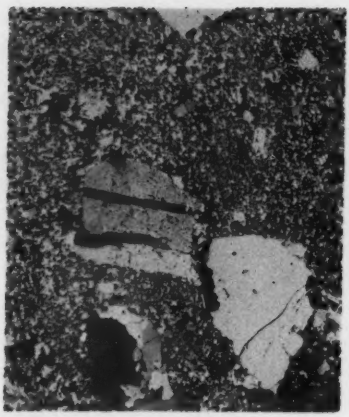

FIGURE 2. CRYSTALS (INTRA-TELLURIC) OF QUARTZ AND OLIGOCLASE
In a quartz-oligoclase-muscovite schist (metamorphosed quartz latite tuff) from Post Pond volcanic member. Nicols crossed (× 14).

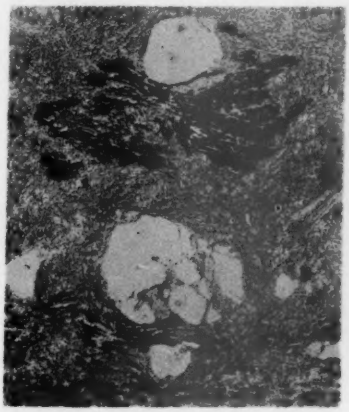

FIGURE 3. FEATHERY GROWTH OF KYANITE
In kyanite schist from Post Pond volcanic member. Large white grains are quartz. Groundmass is composed of quartz, muscovite, and chlorite (amesite). Nicols not crossed (× 14).

FIGURE 4. INCLUSIONS OF QUARTZ AND FELDSPAR IN CENTER OF HORNBLENDE NEEDLES
In a metamorphosed volcanic from the Post Pond volcanic member. Nicols not crossed (× 7).

PHOTOMICROGRAPHS OF ORFORDVILLE FORMATION

FIGURE 1. PORPHYROBLAST OF STAUROLITE
Surrounded by shell of chlorite and muscovite (alteration) in staurolite schist from Littleton formation. Dark band in staurolite is zone of inclusions (mostly quartz). Nicols crossed (× 14).

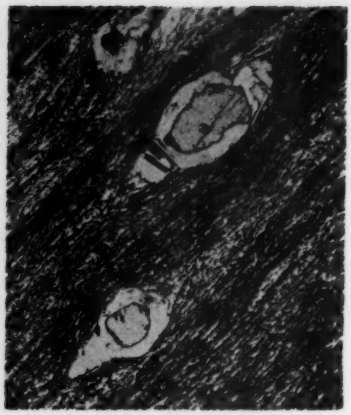

FIGURE 2. PORPHYROBLASTS OF GARNET
Surrounded by thick shells of chlorite (alteration) in mica schist from Littleton formation. Nicols not crossed (× 14).

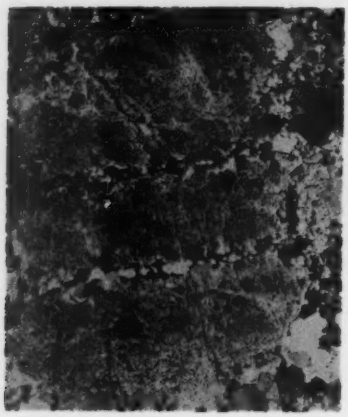

FIGURE 3. FRACTURED PHENOCRYST OF MICROCLINE
In Lebanon granite. Nicols crossed (× 14).

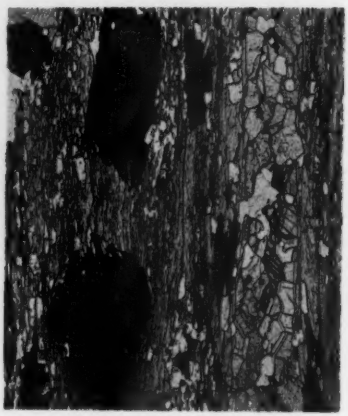

FIGURE 4. PORPHYROBLASTS OF BIOTITE
In layers containing fine-grained chlorite and muscovite in calcareous mica schist from Post Pond volcanic member. Nicols not crossed (× 19).

PHOTOMICROGRAPHS OF ORFORDVILLE AND LITTLETON FORMATIONS AND LEBANON GRANITE

garnet seems to have grown at the expense of chlorite. As no white mica was present in the rock, biotite could not form, and the chlorite was transformed to garnet. The optics on the chlorite are $\beta = 1.653$, birefringence $= 0.006$, optically negative. According to Winchell (1936, p. 649), this indicates an iron-aluminum chlorite (thuringite) with very little magnesium. The index of the garnet is 1.806 and the specific gravity is 4.15. This, according to Winchell (1933, p. 176) is an iron-aluminum garnet (almandite) with a little magnesium and manganese. Such a similarity in composition suggests that the garnet could have formed from the chlorite.

Kyanite.—Kyanite is found in the upper part of the Post Pond member of the Orfordville formation. In the kyanite schists on Signal Hill in Lebanon Township, the kyanite is found only with quartz and muscovite. The rocks on either side of these schists, however, contain biotite, and in places a little garnet. This would indicate that the kyanite schists, here, are well within the middle-grade zone. Northeast of Gleason Cemetery in Plainfield Township, kyanite occurs with quartz, muscovite, and chlorite, but not biotite. It has already been shown how absence of biotite (or phlogopite) may be due, not to low temperature conditions, but to the composition of the chlorite. These rocks are in what is generally considered the biotite zone, but it takes a slightly higher temperature for this particular chlorite (amesite) to combine with the muscovite. The mineral kyanite, therefore, has formed in a much lower grade of metamorphism than first recognized by Barrow (1912, p. 275).

Sillimanite.—Sillimanite is found only in the Littleton formation in the highest grade of metamorphism. It occurs in rocks that are the high-grade equivalent of the staurolite schists. This mineral was one of the last to form as it replaces micas, quartz, feldspar, and garnet.

Staurolite.—Staurolite is restricted to the eastern half of the belt of the Littleton formation, between Mascoma Lake and Cornish. The crystals are usually in well-formed, stout prisms one-half to three inches long. There is a marked increase in size of the crystals as one proceeds from west to east across this belt. In many places the Littleton is composed of beds about a foot thick, some of which contain over a third staurolite whereas others contain little or none. This strongly suggests that staurolite was formed as a result of recrystallization of material already in the rock, and is not due to the introduction of material. Except for this mineral, the two types of beds closely resemble each other. Their chemical differences may lie mainly in the content of alumina. The presence or absence of staurolite cannot be explained as being due to differences in temperature or stress, because of this bedding relationship.

ROTATION OF PORPHYROBLASTS

Many porphyroblasts of biotite and garnet were rotated as a result of slight differential movement which continued after a schistosity had been produced. In some, rotation occurred contemporaneously with crystal growth, whereas in others it followed the formation of porphyroblasts. Evidence of rotation is most clearly seen where the minerals contain elongated inclusions or lines of inclusions, which were oriented parallel to the schistosity when they were enclosed and are now inclined to that schistosity. The fact that most porphyroblasts do not contain elongated inclusions or lines of inclusions and the fact that the plane of the thin section is not always parallel to the plane of rotation of the crystals leads one to believe that perhaps rotated porphyroblasts are much more common than is usually assumed.

The curved bands of inclusions indicate rotation during crystal growth for many of the biotite porphyroblasts, particularly in the Orfordville formation. The amount of this rotation has commonly been as much as 30°. In some specimens the basal cleavage of the biotite is at right angles to the lines of carbon inclusions. This would indicate that the porphyroblasts grew with their basal planes perpendicular to the bedding and schistosity. In the Orfordville schist, numerous porphyroblasts of biotite distort the schistosity, and give the rock a knotted appearance in hand specimen. In thin section the porphyroblasts are seen to be disk-shaped, with margins feathering-out into clear, recrystallized quartz. In spite of the fact that these porphyroblasts distort the schistosity, they originally must have replaced the rock in their entirety, because they contain wavy bands of carbon which represent crinkled bedding (Pl. 4, fig. 1). They may have been subjected to a later deformation which caused them to rotate slightly and distort the schistosity. Thus they might give the appearance of having originally displaced the schistosity. Most of these porphyroblasts show the effects of strain, which is further evidence of a late deformation. Indeed, many show a sharp bending of the cleavage. Several examples have been observed where biotite crystals have been ruptured, and one-half has been pushed far over the other so that the projecting ends distort the schistosity.

Rotated porphyroblasts of garnet are not so common as those of biotite, but they were observed in several thin sections. In one thin section garnets were seen, which contained curved lines of inclusions, indicating rotation during growth. The alignment of inclusions in the centers of these crystals, however, was parallel to the schistosity. It would seem, therefore, that the garnets had either been rotated back into place after formation, or else they had been rotated 180°.

ATTAINMENT OF EQUILIBRIUM

If during the course of progressive metamorphism, the reaction of lower temperature minerals to those of higher temperature is not complete, and equilibrium at a particular temperature and pressure is not attained, a progressive disequilibrium rock will be produced. Such a rock will contain minerals belonging to different zones of metamorphism, but this does not include those minerals formed by retrograde processes.

Some of the Orfordville schists, in which garnet has formed from chlorite, (thuringite) represent rocks of this type. These rocks were probably raised to a temperature above the range of stability for chlorite, and it was converted to garnet. For some reason, however, the reaction did not go to completion, and now both garnet and chlorite exist side by side in the same rock. One mile east of Lebanon Village, in a cut along a new road not shown on the accompanying map (Pl. 6), are schists in which large porphyroblasts of biotite are found imbedded in a fine-grained mixture of chlorite and muscovite. The biotite is scarcely altered, and it does not seem reasonable to suppose, therefore, that the chlorite could be retrograde (Pl. 3, fig. 4). These rocks were probably raised to the temperature where biotite started to form from the chlorite-muscovite mixture, but the conditions were not maintained long enough for all the muscovite and chlorite to react. Therefore, the reaction never went to completion, and a progressive disequilibrium rock was produced.

The two examples just cited are, perhaps, the most striking seen in the Mascoma quadrangle. It should be noted that progressive disequilibrium rocks may be much more common than is generally supposed. Our criteria for determining such rocks depend upon an accurate knowledge of the reactions which take place during metamorphism—a complicated subject in such multi-component systems.

In order to maintain equilibrium certain retrograde changes took place subsequent to the culmination of metamorphism. These changes were marked chiefly by the formation of lower temperature minerals from those of higher temperatures. Undoubtedly the most common effect of retrograde metamorphism is seen in the development of chlorite from biotite. Such a reaction necessitates the removal of potash, but, commonly, the titanium remains in the form of rutile needles enclosed in the chlorite. Chlorite, altered from fine-grained biotite, is common in the Littleton and Orfordville schists, and in some specimens this reaction has completely destroyed all the biotite, giving the rock the appearance of a low-grade type. Porphyroblasts of biotite are not so easily altered as are the finer flakes. The reason for this may be that the larger crystals offer a smaller surface for their size, than do innumerable smaller ones, and, therefore, are less subject to the attach of solutions essential to the

process of chloritization. In the igneous rocks it is also common to find chlorite altered from biotite.

Somewhat less commonly garnet has altered to chlorite. This type of alteration has two particular modifications. The garnet may alter only along fractures within the crystal, or it may alter from the outside inward, thereby producing a protective chlorite shell (Pl. 3, fig. 2).

Crystals of staurolite are seen to be surrounded by a thick shell of muscovite in some specimens. In thin section this shell is clearly seen to have been derived from staurolite, and it is composed of large flakes of muscovite less than a millimeter across. Small amounts of chlorite are also present (Pl. 3, fig. 1). In extreme cases of retrograde metamorphism the whole crystal of staurolite has been converted to a mixture of muscovite and chlorite. Much of the kyanite in the belt of schists, extending north from Signal Hill, in Lebanon Township has been altered to muscovite. Although the kyanite may be completely muscovitized the outlines of the former crystals may still be seen in hand specimens. The transformations of both staurolite and kyanite to muscovite require the addition of potash, and are in a sense hydrothermal.

STAGES IN METAMORPHISM

It has already been shown how a definite schistose structure was developed in the sedimentary and volcanic rocks in the roofs of the Oliverian domes. This process of deformation is believed to have been accomplished by the aid of heat and solutions from the crystallizing magma, and the differential stresses set up by the particular mechanism of doming. It was contact metamorphism, in that heat and solutions from the Oliverian magma played a most important part; it was also dynamic, in that the roof rocks were compressed in a vertical direction and stretched radially in a horizontal direction.

At some time previous to the period of folding or during an early stage of folding, a schistose structure seems to have been developed on some of the rocks of the Orfordville formation. This structure was parallel to the bedding and may have formed merely by the recrystallization of micaceous material at low temperatures, under the weight of thousands of feet of sediments. Noll (1932) has shown that muscovite may crystallize from jell-like substances at temperatures as low as 225° C., and Barth (1936, p. 780) states

> ". . . as the rate of crystallization is slow and as no long runs were made by Noll, probably the low-temperature limit is even lower."

It is conceivable, therefore, that without any heat other than that given by the thermal gradient the micaceous material, in the presence of some connate water, would crystallize to form muscovite. Under the weight

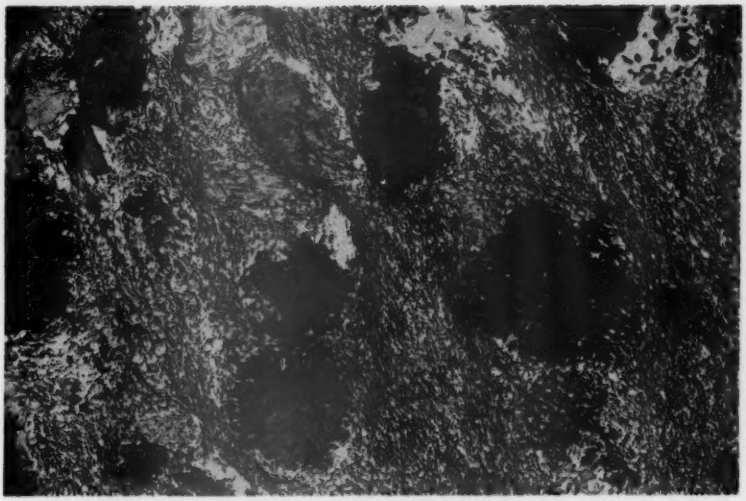

FIGURE 1. PORPHYROBLASTS OF BIOTITE
Enclosing wavy bands of carbonaceous material (probably original bedding) and distorting schistosity in mica-quartz schist from Orfordville formation. Nicols not crossed (× 19).

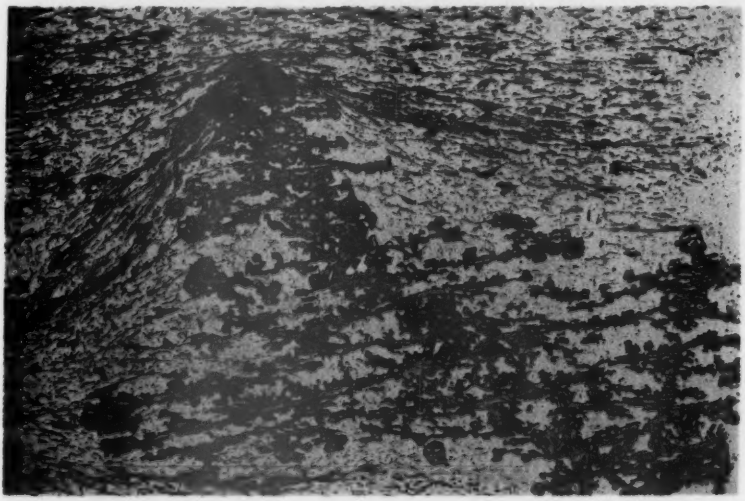

FIGURE 2. SKELETAL GROWTH OF GARNET AND DISTORTION OF MICA LAYERS
In mica-quartz schist from Orfordville formation. Nicols not crossed (× 19).

PHOTOMICROGRAPHS OF ORFORDVILLE FORMATION

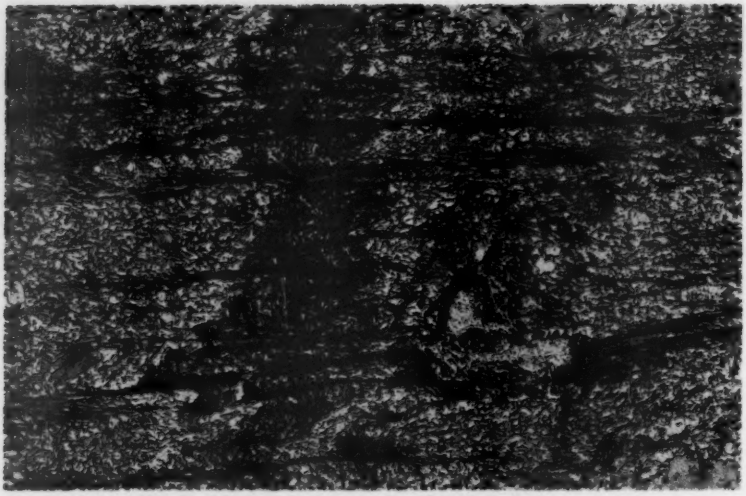

FIGURE 1. "SLIP CLEAVAGE" AT RIGHT ANGLES TO BEDDING
In mica-quartz schist from Orfordville formation. Traces of an older schistosity may be seen parallel to bedding (vertical). Micas of old schistosity have been bent and curved. Nicols not crossed (× 30).

FIGURE 2. "SLIP CLEAVAGE" AT RIGHT ANGLES TO BEDDING
In mica-quartz schist from Orfordville formation. Garnet crystal in center replaces rock. Where garnet replaces mica of shear zones, inclusions are absent but abundant elsewhere. Some traces of older schistosity may be seen parallel to bedding (horizontal). Nicols not crossed (× 12).

PHOTOMICROGRAPHS OF ORFORDVILLE FORMATION

of at least 11,000 feet of sediment, a schistose structure might be produced parallel to the bedding.

This original schistosity has been lost in most places, but it has been observed where the regional schistosity cuts across the bedding, as for example on the nose of a fold. Elsewhere the two schistosities are probably parallel. In one specimen, taken at the nose of a fold, the regional schistosity was actually a "slip-cleavage," developed at right angles to the bedding. Displacement along these cleavage planes caused a "slip folding" of the bedding and older schistosity (Pl. 5, fig. 1). The micas have been recrystallized along the new planes of shear, but elsewhere they have been somewhat rotated from their original position. The earlier schistosity and the bedding can still be traced across the thin section. Garnet crystals up to a millimeter across are abundant, and seem to have replaced only the mica (Pl. 5, fig. 2). That part of the garnet crystal in the shear zone is homogeneous, because this zone originally contained only mica. Those parts of the garnet crystal outside the shear zone, however, are filled with inclusions of quartz. Here the garnet replaced only the mica, and left the quartz as inclusions. By this process of selective replacement both early and late structures are preserved in the porphyroblasts.

As folding continued after the development of the Northey Hill thrust, a regional schistosity was developed upon the sedimentary and volcanic rocks of western New Hampshire. Billings (1937, p. 557) has shown that since the degree of folding and depth of burial of these rocks was nearly uniform throughout the region, one must explain the marked increase in metamorphism toward the southeast as due to the proximity of large igneous bodies which were intruded in the late stages of folding. These plutonic bodies belong to the New Hampshire magma series and are represented chiefly by the Bethlehem gneiss and Kinsman quartz monzonite (Billings, 1937, p. 506). The main rôle of these intrusives was to furnish heat and solutions, and aided by differential stresses, a progressive increase in the intensity of metamorphism toward the southeast was accomplished. There is no indication that much magmatic material was introduced, and it seems correct to assume that only water and heat were necessary for the rearrangement of material already present in the rocks.

This will explain the middle-grade and high-grade rocks in the Mascoma quadrangle. The most intense metamorphism occurred in the Littleton schists in the southeastern part of the quadrangle where the rocks lay between the two plutonic masses of the New Hampshire magma series.

TECTONIC SUMMARY AND CONCLUSIONS

Sometime after the deposition of the Littleton formation, the Oliverian magma series was intruded to form laccoliths in the upper part of the

Ammonoosuc volcanics, along what is now known as the Bronson Hill anticline. With the formation of these intrusive bodies, a schistosity developed in the roof sediments, parallel to the bedding, and contemporaneously, in the igneous rocks, a foliation was produced. The schistosity and foliation were parallel and concentric. Perhaps at the same time a stock-like mass, composed of the Lebanon group, was intruded into the Post Pond volcanics. The upward push of the magma, as in the case of the laccoliths, domed and metamorphosed the roof sediments, and produced a concentric foliation in the igneous rock itself. A later intrusion formed the central core of Lebanon granite. This granite is less gneissic, but shows effects of granulation.

During the late Devonian folding began and the Salmon Hole Brook syncline was formed. Eventually the eastern limb of the syncline broke and the Northey Hill thrust developed. The whole western block was relatively overthrust to the east and came to rest high upon the flank of the Bronson Hill anticline. The fault plane itself became crumpled as folding continued after thrusting, and the intensely contorted sediments were dynamically metamorphosed. During the early stages of folding the roofs of the Oliverian domes were crumpled. These igneous bodies must have protected the immediately surrounding rocks from crumpling to a considerable extent, but the effects of regional folding penetrated, for at least a short distance, down into the domes. The folded Clough formation and the Ammonoosuc volcanics on the Croydon dome are illustrative of the effect of a later folding on the roof rocks. Where folding was most intense, as on the southwestern flank of the Mascoma dome, the rocks were isoclinally folded. The superposition of a regional schistosity on the rocks surrounding the Lebanon intrusive destroyed most signs of any previous structure, and to a certain extent, the effects of this dynamic metamorphism extended down into the border gneiss.

Potash-rich solutions are believed to have risen from below the Mascoma dome, and to have replaced much of the original quartz diorite and granodiorite with metacrysts of microcline. Thus, these igneous rocks are believed to have been converted into rocks with compositions equivalent to quartz monzonite and granite. The solutions penetrated, for a few hundred feet, out into the Clough formation on Moose Mountain, converting the quartzite to a rock with the composition of granite.

Near the close of the period of folding, the Bethlehem gneiss (New Hampshire magma series) was intruded, as a huge sheet, at the base of the Littleton formation. Developing a foliation more or less parallel to its walls, it forced its way up over the northern end of the Croydon dome and the southern end of the Mascoma dome, and down the western flank of the Bronson Hill anticline. While some shearing stresses still persisted, the heat and solutions (chiefly water) from this crystallizing mass and

others farther east in New Hampshire are supposed to have raised the temperature of the rocks in the Mascoma quadrangle, and produced rocks characteristic of the middle grade zone of metamorphism. The rocks of the Littleton formation, which lay between the Bethlehem gneiss on the west and the slightly younger mass of Kinsman quartz monzonite on the east, were raised to the temperature conditions characteristic of high-grade metamorphism. As a result, the alumina-rich beds were converted to sillimanite schists and the rocks as a whole developed a much coarser texture.

Perhaps in Carboniferous time numerous dikes and two small bodies of the White Mountain magma series were intruded. It was not possible to determine the period of formation of the normal fault extending from Enfield Village to past North Grantham. The fault is probably younger than late Devonian as it displaces the Bethlehem gneiss which is believed to be of that age.

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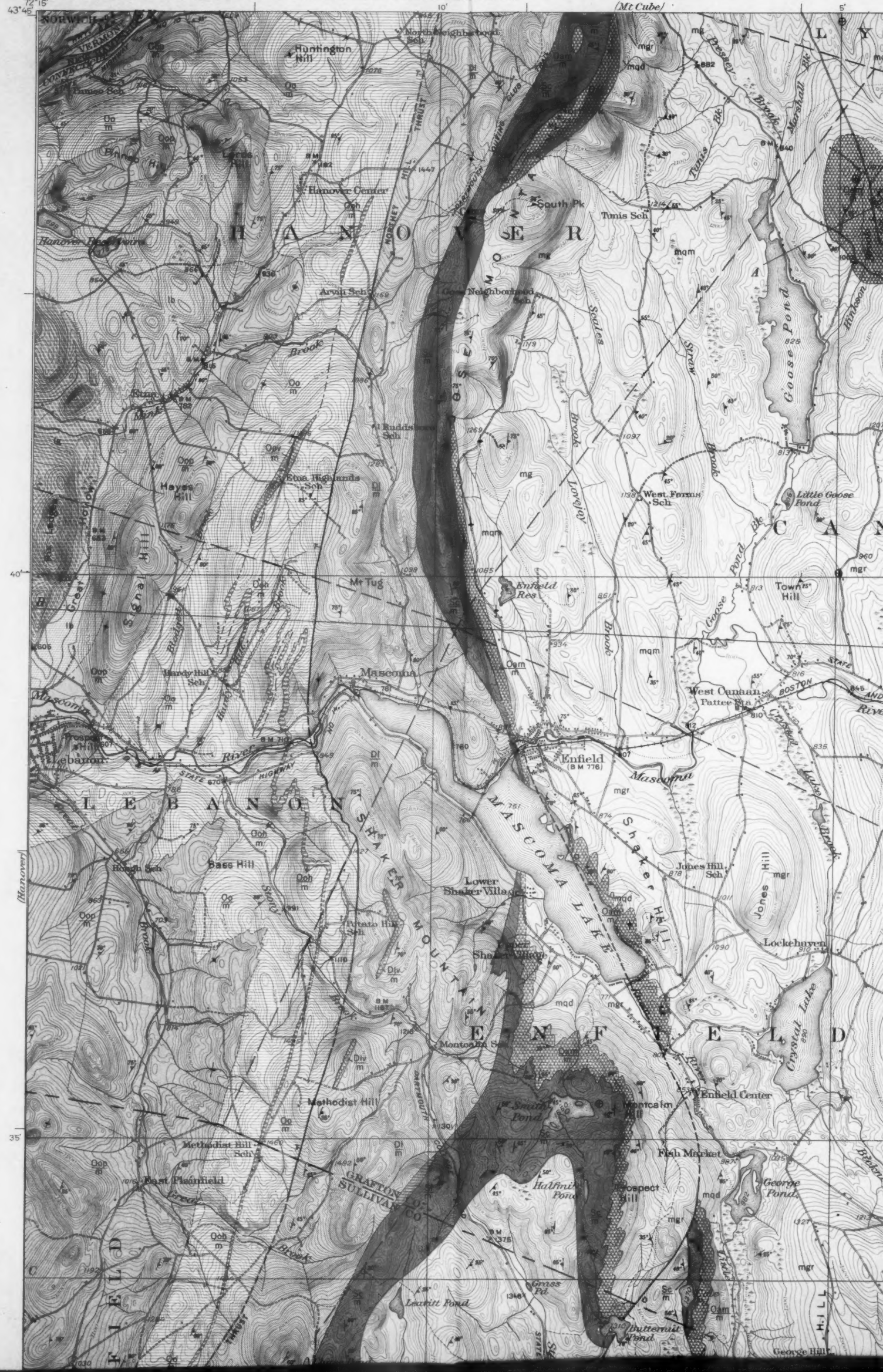
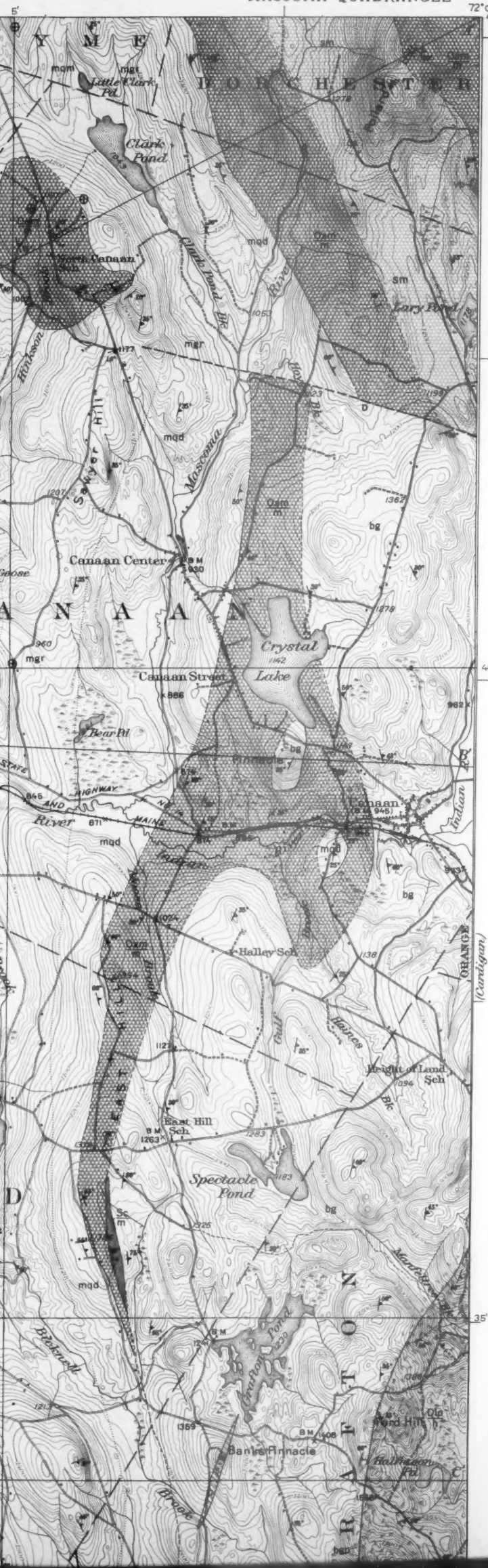


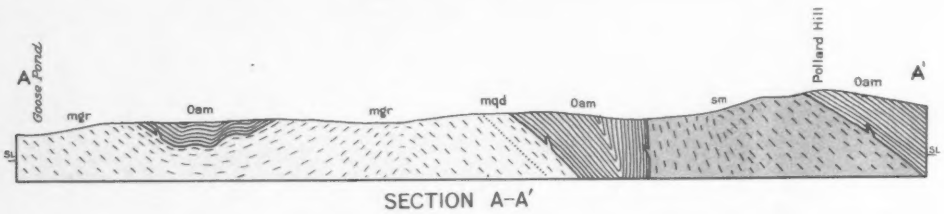
NEW HAMPSHIRE
MASCOMA QUADRANGLE



LEGEND

SEDIMENTARY, IGNEOUS, AND METAMORPHIC ROCKS

PROBABLY CARBONIFEROUS	*Post-folding*		qs — **Quartz syenite** *(Medium-grained, massive, green, quartz syenite, composed of antiperthite, quartz, perthite, oligoclase, and biotite; small amounts of hastingsite and pyrite; weathered to a coarse, residual soil.)*
	White Mountain Magma Series		vb — **Volcanic breccia** *(Filling a volcanic neck; composed of trachytic tuff; locally contains angular fragments, up to a foot in diameter, of quartz syenite, Ammonoosuc volcanics, and Smarts Mountain type of quartz diorite.)*
YOUNGER THAN LOWER DEVONIAN	*End of folding*	*New Hampshire Magma Series*	pgp, bg — **Bethlehem gneiss** *(Medium- to coarse-grained, gray orthogneiss, composed of andesine, quartz, biotite, microcline, and a little muscovite; usually granodiorite, but locally quartz monzonite or granite. bgp, areas where pegmatites cutting Bethlehem gneiss are abundant.)*
			mqd, mgr, mqm, mg — **Mascoma group** *(Fine- to medium-grained, white, gray, and pink, weakly foliated, granitoid rocks, composed of oligoclase, quartz, microcline, and biotite. mqd, quartz diorite; mgr, granodiorite; mqm, quartz monzonite; mg, granite.)*
			sm — **Smarts Mountain group** *(Fine-grained, white to gray, weakly foliated quartz diorite and granodiorite; composed of oligoclase, quartz, biotite, hornblende, and microcline.)*
PROBABLY LATE DEVONIAN	*Pre-folding, various groups contemporaneous*	*Oliverian Magma Series*	c — **Croydon group** *(Fine-grained, white to gray, weakly foliated quartz diorite and granodiorite; composed of oligoclase, quartz, biotite, and microcline.)*
			lb, lg — **Lebanon group** *(lg, Lebanon granite, a medium- to coarse-grained, pink, subporphyritic, somewhat granulated granite and gneissic granite, composed microcline, quartz, oligoclase, biotite, epidote, and muscovite. lb, border gneiss, a fine- to medium-grained, dark-gray, granulated gneiss; composed of oligoclase, quartz, biotite, epidote, microcline, hornblende, and muscovite.)*
DEVONIAN	*Lower*		Dl, Dlp, Dlv — **Littleton formation** *(Zone m: quartzite, mica-quartz schist, mica schist, and staurolite schist, with medium-grained biotite-gneiss of volcanic origin. Dlv. Zone h: mica schist, mica-quartz schist, and sillimanite schist. Dlp, areas where pegmatites cutting Littleton formation are abundant.)*
SILURIAN	*Middle*		Sf — **Fitch formation** *(Zone m: thin-bedded, fine- to medium-grained diopside-epidote-microcline granulite and microcline-hornblende-epidote-diopside granulite.)*
	Lower or Middle		Sc — **Clough formation** *Zone m: chiefly quartz conglomerate and quartzite, with some mica-quartz schist and mica schist.)*
			UNCONFORMITY
PRE-SILURIAN, PROBABLY ORDOVICIAN	*Upper Ordovician?*		Oam — **Ammonoosuc volcanics** *(Zone m: chiefly amphibolite, with some fine-grained biotite gneiss.)*
			Lower part of Ammonoosuc volcanics, all of Albee formation, and upper part of Orfordville formation, which are present elsewhere, are missing in this quadrangle due to the Northey Hill thrust.
	Middle Ordovician?		Ooh, Oo, Oov, Oop — **Orfordville formation** *(Zone m: Black to dark-gray mica-quartz schist, mica schist, garnet schist, and quartzite; Hardy Hill quartz member, Ooh, consists of gray to white quartzite and quartz conglomerate, with some quartz-mica schist and mica schist; where Hardy Hill quartzite is very thin or absent, its horizon is shown by a dash-dot line. Post Pond volcanic member, Oop, consists of fine-grained gneiss, schist, and amphibolite, of volcanic origin, and quartzite, mica-quartz schist, mica schist, and kyanite schist, of sedimentary origin. Small volcanic lenses, Oov, other than the*



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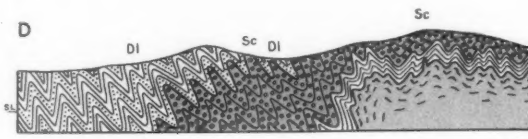

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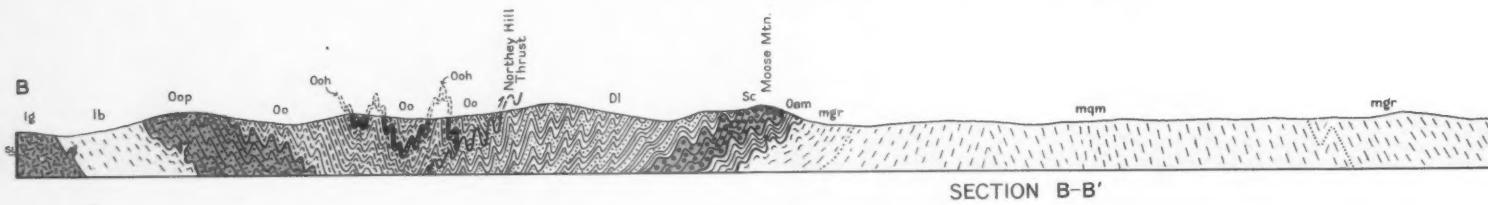

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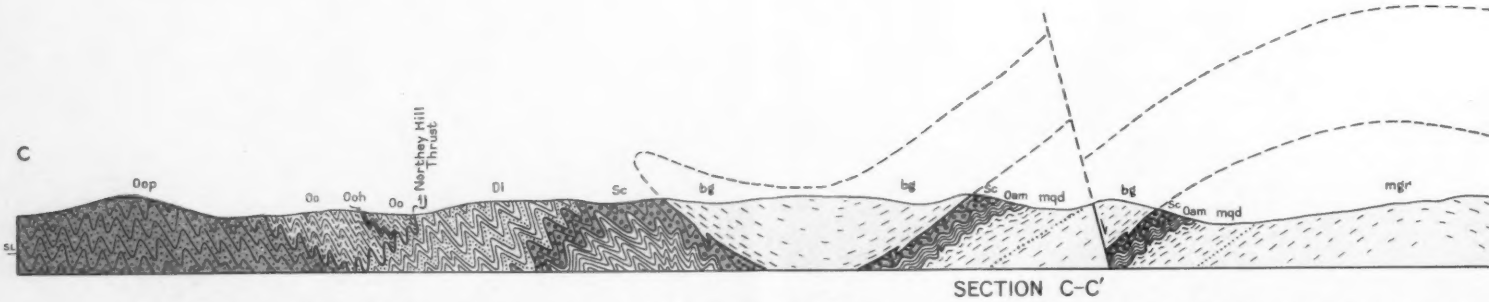


SECTION C–C'

GEOLOGIC MAP AND STRUCTURE SECTIONS OF THE MASCOMA QUADRAN

Topographic base by U. S. Geological Survey, surveyed in cooperation with the State of New Hampshire.

Scale 1/62500

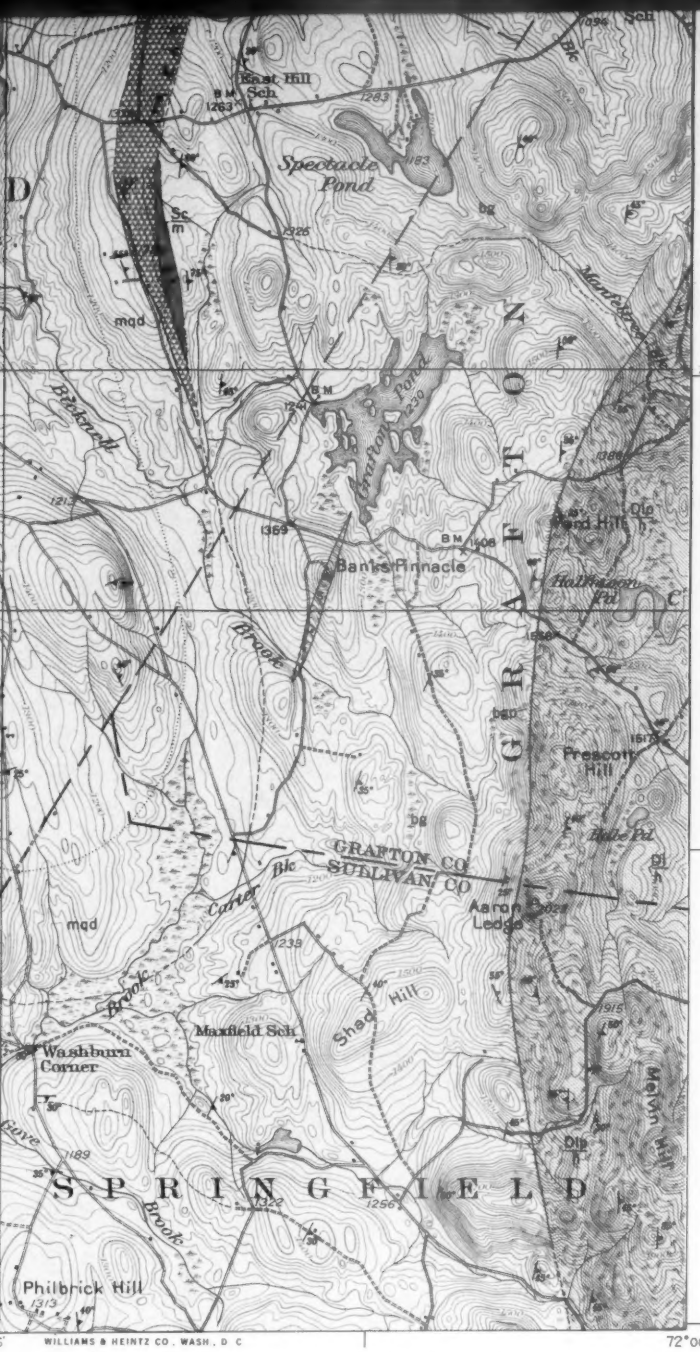
1 0 1 2 3 4 Miles

5000 0 5000 10000 15000 20000 Feet

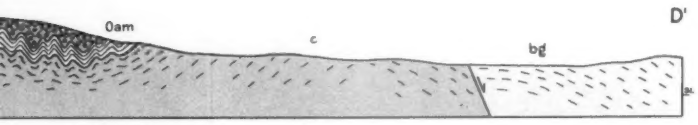
1 0 1 2 3 4 5 Kilometers

Contour interval 20 feet

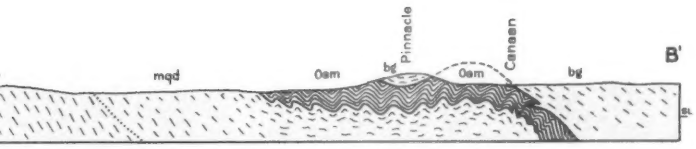
Datum is mean sea level

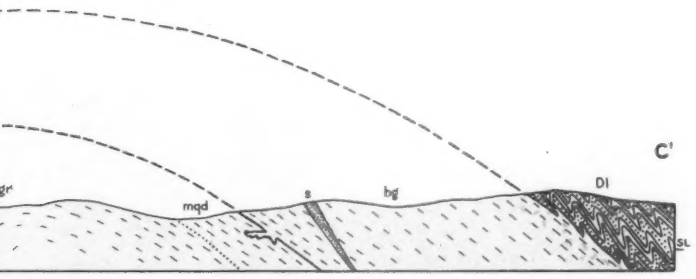


(Mt. Kearsarge)



SECTION D–D'





DRANGLE, NEW HAMPSHIRE

Miles
Feet

Geology by Carleton A. Chapman, assisted by Bernard Chapman Richard Vosburgh, and Edgar Breed, Jr. Directed by Marland Billings. Geology surveyed in 1935 and 1936, under the auspices of the Division of Geological Sciences, Harvard University, with the aid of grants from the Holden Fund. Published 1938.

SILURIAN

PRE-SILURIAN, PROBABLY ORDOVICIAN

Lower or Middle

hornblende-epidote-diopside granulite.)

Sc

Clough formation

Zone m: chiefly quartz conglomerate and quartzite, with some mica-quartz schist and mica schist.)

UNCONFORMITY

Upper Ordovician?

Oam

Ammonoosuc volcanics

(Zone m: chiefly amphibolite, with some fine-grained biotite gneiss.)

Lower part of Ammonoosuc volcanics, all of Albee formation, and upper part of Orfordville formation, which are present elsewhere, are missing in this quadrangle due to the Northey Hill thrust.

Middle Ordovician?

Oo
Ooh
Oov
Oo
Oop

Orfordville formation

(Zone m: Black to dark-gray mica-quartz schist, mica schist, garnet schist, and quartzite; Hardy Hill quartz member, Ooh, consists of gray to white quartzite and quartz conglomerate, with some quartz-mica schist and mica schist; where Hardy Hill quartzite is very thin or absent, its horizon is shown by a dash-dot line. Post Pond volcanic member, Oop, consists of fine-grained gneiss, schist, and amphibolite, of volcanic origin, and quartzite, mica-quartz schist, mica schist, and kyanite schist, of sedimentary origin. Small volcanic lenses, Oov, other than the Post Pond member, consist of fine-grained gneiss, schist, and amphibolite.)

METAMORPHIC ZONES

Shown below formation symbol thus: $\frac{Dl}{m}$

m-middle grade

h-high grade

CONTACTS

Accurate

Approximate and diagrammatic due to poor exposures

Indefinite as sharp contact is lacking

SPECIAL SYMBOLS

(Dip and strike symbols representing only a small percentage of the field observations)

75° — Strike and dip of bedding, including inverted and normal strata

Strike of vertical beds

75° — Strike and dip of foliation and schistosity

Strike of vertical foliation and schistosity

Horizontal foliation and schistosity

Overthrust side of thrust faults

D — D, Downthrown side of normal faults

S — Silicified fault zone

Mines, prospects, and quarries mostly abandoned